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The Ohio State University Version of the Stanford Streamflow Simulation Model

PART I —
TECHNICAL ASPECTS

PART II —
THE COMPUTER PROGRAM

PART III —
USER'S MANUAL

By
Vincent T. Ricca
Professor of Civil Engineering

SECOND PRINTING
JUNE 1974

State of Ohio
Water Resources Center
Ohio State University

The many requests for The Ohio State University Version of the Stanford Streamflow Simulation Model, Part I, II, III have completely exhausted the supply from the first printing and the writer wishes to acknowledge the support of the Water Resources Center for a second printing. The report has been reproduced in its original form and bound in a single compilation.

Columbus, Ohio

V. T. Ricca

July 1974

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PART I —
TECHNICAL ASPECTS
MAY 1972

By
Vincent T. Ricca
Associate Professor
of Civil Engineering

Office of
Water Resources Research
United States Department
of the Interior

PROJECTS
B-005-OHIO
B-019-OHIO

State of Ohio
Water Resources Center
Ohio State University

THE OHIO STATE UNIVERSITY VERSION

of the

STANFORD STREAMFLOW SIMULATION MODEL

PART I - TECHNICAL ASPECTS

Principal Investigator

Vincent T. Ricca
Associate Professor
Department of Civil Engineering

THE OHIO STATE UNIVERSITY

Columbus, Ohio 43210

OFFICE OF WATER RESOURCES RESEARCH
U. S. Department of the Interior
Matching Grants B-005-OHIO, B-019-OHIO

May 1972

THE OHIO STATE UNIVERSITY VERSION

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STANFORD STREAMFLOW SIMULATION MODEL

PART I - TECHNICAL ASPECTS

ABSTRACT

Research with the Stanford Streamflow Simulation model at The Ohio State University has been performed along these lines: starting with the University of Kentucky version a detailed expose and computer flow charting of the model was written; the model was applied to small agricultural watersheds as a basis for a sensitivity study of the major variable input parameters; and a subroutine was developed for superimposed machine plotting of the hydrographs.

Efforts to improve the model were as follows: modification of the time of concentration increments to handle small (approx. 100 acre) watersheds; development of a snowmelt subroutine for climatological conditions unique to the Midwest region; expansion of the model to accommodate multiple groundwater recession constants for basins with a stratified geology; inclusion of swamps and soil crack storage consideration; and machine plotting of hyetographs to accompany the hydrograph plots.

All modifications have been tested with the data of the USDA North Appalachian Experimental Watershed at Coshocton, Ohio, with reasonably good results.

The salient features of these modifications and their application are reported herein.

KEY WORDS

Descriptors: Simulation/ Hydrologic Models/ Computer Models/ Streamflow Forecasting/ Evapotranspiration/ Hydrograph Analysis/ Sedimentary Basins/ Snowmelt/ Time of Concentration/ Small Watersheds/ Agricultural Watersheds.

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The Ohio State University,
Columbus, Ohio

HYDROLOGIC INVESTIGATIONS OF SMALL WATERSHEDS IN OHIO

Research With the Stanford Streamflow Simulation Model

1968-1972

PROJECT PERSONNEL

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PREFACE

The Ohio State University Version Of The Stanford Streamflow Simulation Model

For convenience of reading and handling, ease of extending or updating, and to suit the reader's particular interest, the publication of the material associated with this model will be reported in three separate volumes.

The volume titles and a brief account of their content are:

The Ohio State University Version of the Stanford Streamflow Simulation Model:

Part I -- Technical Aspects:

A detailed analytical and descriptive presentation of the basic model with discussions on the input and output options, modifications made, test applications, performance evaluation, and developmental topics for future research.

Part II -- The Computer Program:

Definition of program variables (386) and listing of the program statements (1881).

Part III -- User's Manual:

A working understanding of the model so that the potential user can use it efficiently and effectively as a tool in hydrologic investigation.

The technical details in Part I are needed if one wishes to study the basic operation of the model, in particular, if modifications or additions are planned. For the practicing engineer or researcher Parts II and III will suffice for successful running of the model.

The author would appreciate receiving comments concerning both applications of the model and modifications to its structure. Feedback of this nature would be useful for compiling data on the ranges of the initializing parameters with eventual inclusion in updated versions of the User's Manual.

ACKNOWLEDGEMENTS

The work performed in this report has been an interdisciplinary research effort involving faculty, students, and researchers from two branches of U. S. Department of Agriculture.

The report was compiled from six Master of Science theses (Balk, 1968, Briggs, 1969; Owen, 1970; Mease, 1970; Valentine, 1970; and Warns, 1971) from the Department of Civil Engineering, The Ohio State University.

Assistance by Dr. E. U. Nwa, Research Associate, in reviewing the theses, compiling the findings, and writing this report is greatly appreciated.

This study was a portion of a research project, Hydrologic Investigations of Small Watersheds in Ohio, administered by Dr. E. Paul Taiganides, Project Director, Department of Agricultural Engineering, The Ohio State University.

This research was aided by faculty colleagues: Drs. E. P. Taiganides, G. O. Schwab, and M. Y. Hamdy, Professors of Agricultural Engineering, and Dr. G. P. Hanna who at the time served as Director of the Water Resources Center, The Ohio State University. Their counsel and service on thesis reading committees was most helpful.

Many thanks are given to staff of the North Appalachian Experimental Watershed, Coshocton, Ohio, for their encouragement, cooperation, and inexhaustible efforts to supply test data. Mr. L. L. Harrold, Officer-in-Charge and Adjunct Professor of Agricultural Engineering was an inspiration to the students and member of their theses reading committee. Mr. J. L. McGuinness, Statistican, supplied much of the test data and assisted in the analysis and interpretation of the modeling results. Dr. W. Edwards, Soil Physicist, freely shared his knowledge of the test watershed soils. In the earlier stages, Mssrs. C. R. Amerman, Watershed Engineer, and J. B. Urban, Geologist, were instrumental in initiating the study.

Gratitude is expressed to Mr. H. N. Holton and his staff of the USDA Hydrograph Laboratory in Beltsville, Maryland. They assisted in determining some of the modeling parameters and supplied their reduced data on the test watersheds. Correspondence and meetings with this group provided much guidance during our endeavors.

Of course this entire project could not have been possible if it were not for the cooperation of Professors N. H. Crawford and R. K. Linsley, originators of the model and Dr. L. D. James, who unselfishly gave us his translated version of the model and provided guidance and encouragement throughout this project.

The consultation provided by the staff of The Ohio State University Numerical Computations Laboratory was indispensable during the computer program check-out.

Financial support for this project came from several sources: The Office of Water Resources Research, U. S. Department of the Interior; Matching Fund Grants B-005-OHIO and B-019-OHIO; The Ohio State University Departments of Civil Engineering and Agricultural Engineering; and Graduate Student Traineeships, Federal Water Pollution Control Administration, U. S. Department of the Interior.

Special thanks are due to the staff of The Ohio State University Water Resources Center, Dr. K. S. Shumate, Director, for their administrative assistance.

Finally, I would like to thank Miss M. Borel for her consistently splendid efforts in typing the manuscript.

Columbus, Ohio

Vincent T. Ricca
Principal Investigator

INTRODUCTION

Streamflow Simulation Models

A dictionary definition of a model is given by Webster as "a system of postulates, data, and inferences, presented as a mathematical description of an entity or state of affairs." The major objective in modeling the hydrologic behavior of a watershed is to simulate its streamflow hydrograph in response to an input of precipitation. To accomplish this, the hydrologic cycle is analyzed and expressed as a collection of mathematical formulations based on rational parameters that may be adjusted after trial simulations with known input and output. This may be continued until the model is judged to be an adequate representation of the hydrologic cycle for a study area.

The Stanford Watershed Simulation Model, a mathematical model programmed for the digital computer, synthesizes a continuous hydrograph (watershed outflow vs. time) of streamflow from climatological data (precipitation and evaporation), and watershed parameters (soil surface moisture and retention properties, interflow storage and flow conditions, ground water storage and flow conditions, and the physical state and geomorphological properties of the basin).

Streamflow simulation models have numerous engineering applications. They conceivably could be a great aid in: the analysis of water resources systems; the assessment of induced climatological changes; quantifying the effects of land use, such as urbanization, upon the hydrology of the area; the evaluation of structural modifications on stream channels; the extension of short-term streamflow records from long-term precipitation records; and among others, the classroom teaching of hydrology.

Evolution Of The Ohio State University Version Of The Model

The Stanford Watershed Model IV was developed by Crawford and Linsley (1966) at Stanford University and published as a technical report in 1966. The model was programmed in ALGOL language by its originators.

Dr. L. D. James, while at the University of Kentucky, translated the model into FORTRAN language and began to make modifications of its structure to suit his interest in its applications to urban watersheds. Among his initial modifications were the simplifications in input data and variable routing procedures. A copy of this translated version was the basic model upon which research efforts began at The Ohio State University.

Over a four year period, through the efforts of faculty researchers, graduate students, and support from the Office of Water Resources Research, the following major steps were performed at The Ohio State University to progress the model to its present state.

i. The computer program was carefully studied, flow diagrammed in detail and an expose on the mechanics of its operation written by Balk (1968);

ii. Machine plotted superimposed (recorded and simulated) hydrograph programs were developed by Briggs (1969);

iii. A sensitivity study of the key parameters was made by Briggs (1969);

iv. Multiple recession constants and a swamp and soil crack storage routines were added by Owen (1970);

v. A snowmelt subroutine for the Midwest was developed by Mease (1970),

vi. Small watershed simulation was made possible by inclusion of a variable time increment modification by Valentine (1970);

vii. Additional output of key internal parameter values and machine plotting of hyetographs was performed by Valentine (1970); and

viii. A compilation study of the above steps was made and a user's manual was written by Warns (1971).

Purpose, Format, and Scope of the Report

PURPOSE

The purpose of this report is to present a logical and concise detailed explanation of the analytical structure of the Ohio State Univesity Version of the Stanford Streamflow Simulation Model. Much work has been done in developing the model over the past few years and it is felt that at this time the model is sufficiently operational and reliable to permit extehsive applications, particularly to the smaller (1 to 50 sq. mile) size waterhseds in the Midwestern United States. The original and other versions of the model have been enjoying successful applications for large watersheds for many years now. Understanding the technical aspects of the model is a prerequisite to those researchers who may want to modify its structure to incorporate the newest concepts or mathematical description of the components involved in hydrologic behavior of a watershed. Much interest is prevalent today for combining water quality and quantity models in order to predict a continuous timewise trend of the water quality from a basin. Detailed knowledge of the model's technical aspects is mandatory for such mating to be possible.

FORMAT

The format of the presentation will be to present, whenever feasible, the model's equations by using the actual FORTRAN programming language statements and their associate variable definitions so that the reader can immediately get involved in the program as it models the components of the hydrologic cycle. Plots of the simulated hydrographs are included where appropriate so that the reader can observe the behavior of the model in response to the particular parameter under discussion.

SCOPE

This report considers in a descriptive and analytical fashion the following technieal aspects of the Ohio State University Version of the Stanford Streamflow Simulation Model

i. Discussions of the basic components of the model;

ii. A review of the input and output options;

iii. Presentation of the modifications made;

iv. An application to Ohio watersheds;

v. Results and discussion of the model's performance; and

vi. Conclusion and recommendations of topics worthy of further development in the model.

For a more in depth discussion of the various topics considered in this report the readers are urged to read the appropriate specific references listed at the end of this report.

This report is Part I -- The Technical Aspects, of a three part report on The Ohio State University Version of the Stanford Streamflow Simulation Model.

The follow up parts are:

Part II -- The Computer Program

Part III --- User's Manual.

HYDROLOGIC CONCEPTS OF THE WATERSHED MODEL

The Hydrologic Cycle and Its Modeled Counterparts

Water is continuously being transported from the oceans to the land and back to the ocean, this cyclic process is known as the hydrologic cycle. The major components of this cycle include precipitation, interception, surface storage, evapotranspiration, infiltration, soil moisture, interflow, groundwater flow, overland flow, and channel flow. Figure 1 is a schematic showing the components of the cycle as well as some of the conceptual terms to be used in modeling.

Figure 2 shows the timewise distribution behavior of the portion of the hydrologic cycle involving the phenomenon associated with the precipitation falling on the earth's surface. The shaded area represents the fraction of total rainfall which eventually produces a hydrograph of streamflow.

In essence the watershed model is designed such that the various components and associated phenomena of the hydrologic cycle are mathematically described and incorporated in a master computer program. The program will keep a chronological account of the quantities of moisture allocated to the various components of the cycle.

Thus from an input of precipitation (quantity/time, inches/hr) the model will generate the basin's response or streamflow (cu. ft./sec.). These are the major input and output. However, all the individual cycle components are considered in the model and these may be examined as supplementary output.

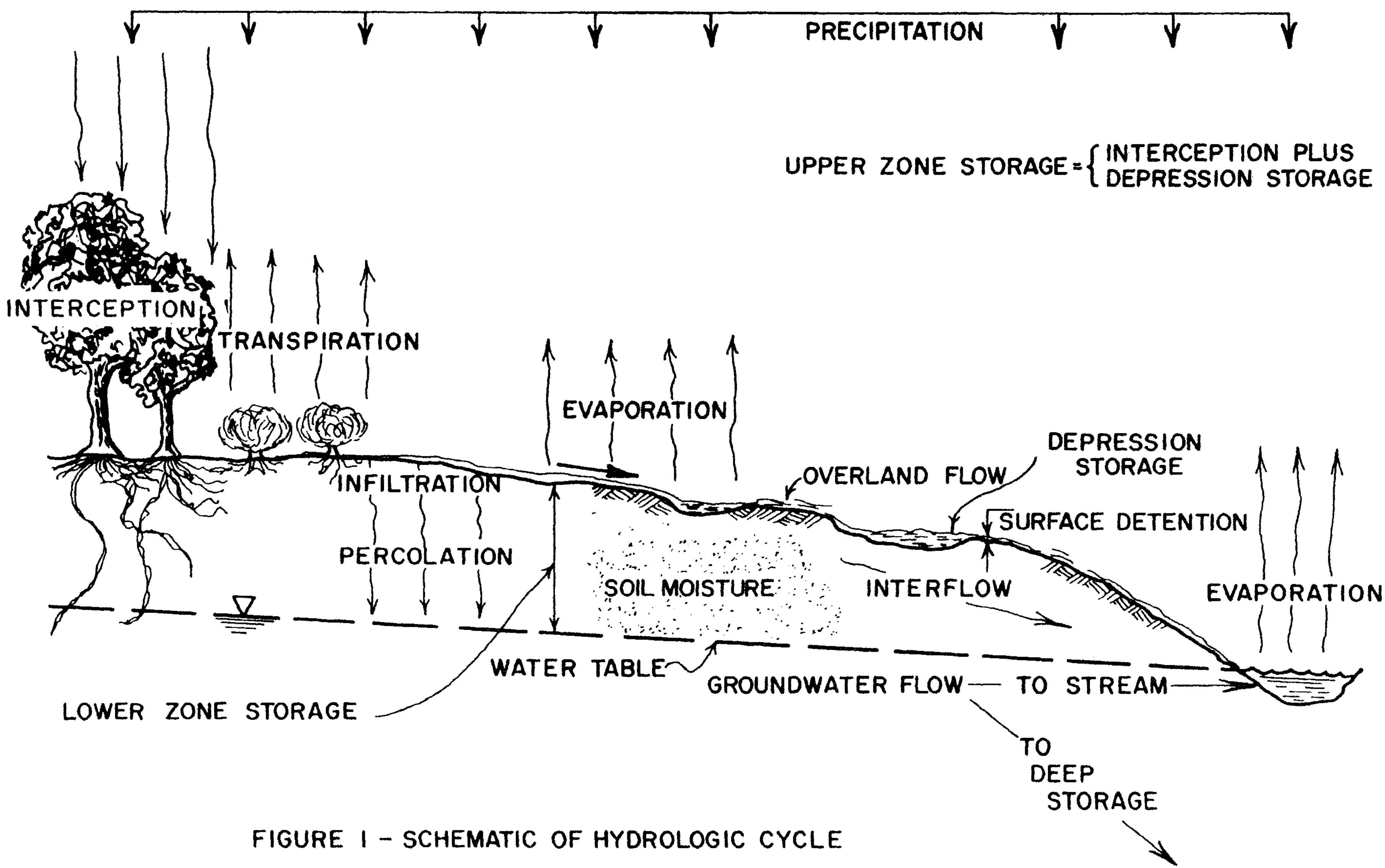


FIGURE 1 – SCHEMATIC OF HYDROLOGIC CYCLE

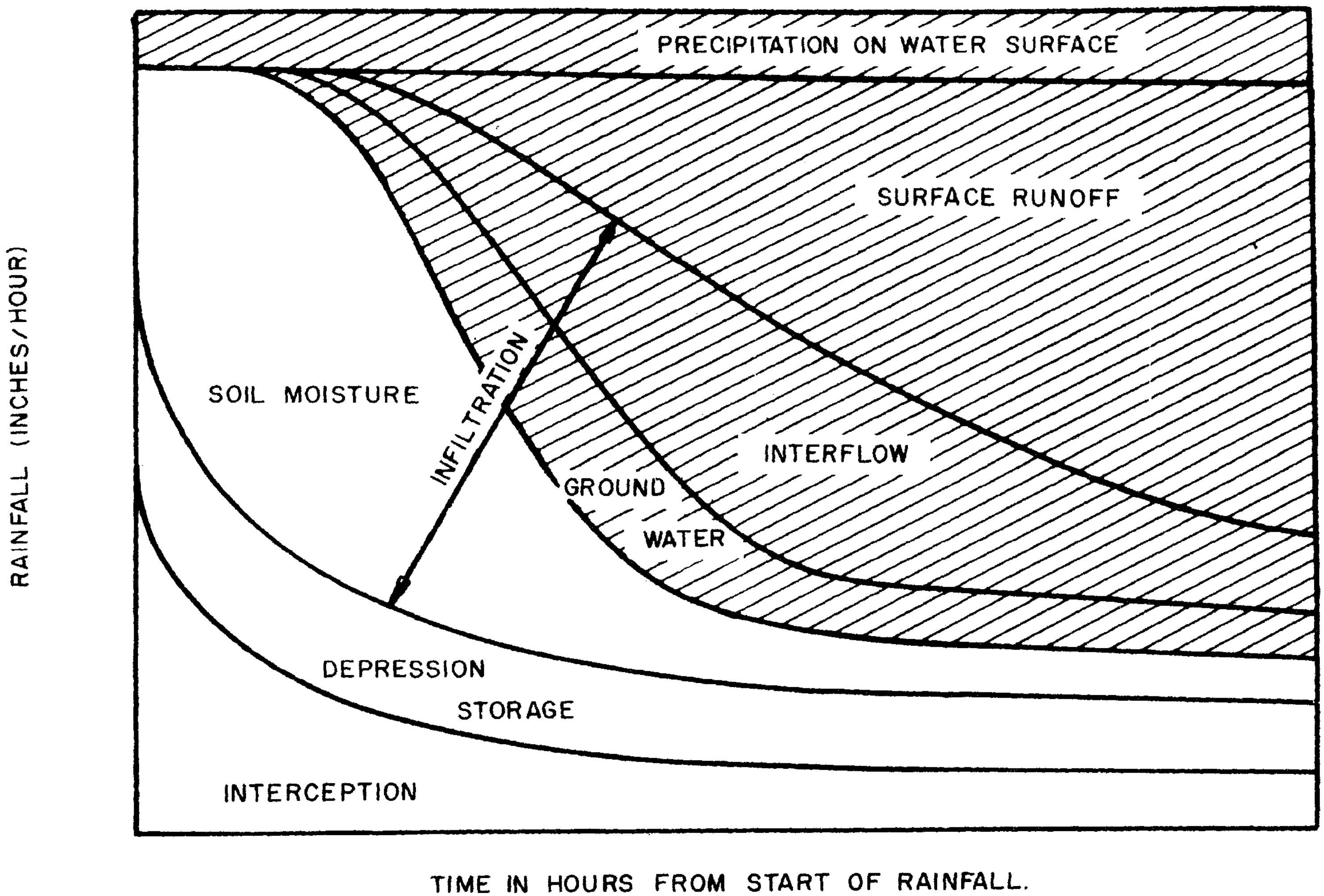


FIGURE 2. WATERSHED RESPONSE TO RAINFALL

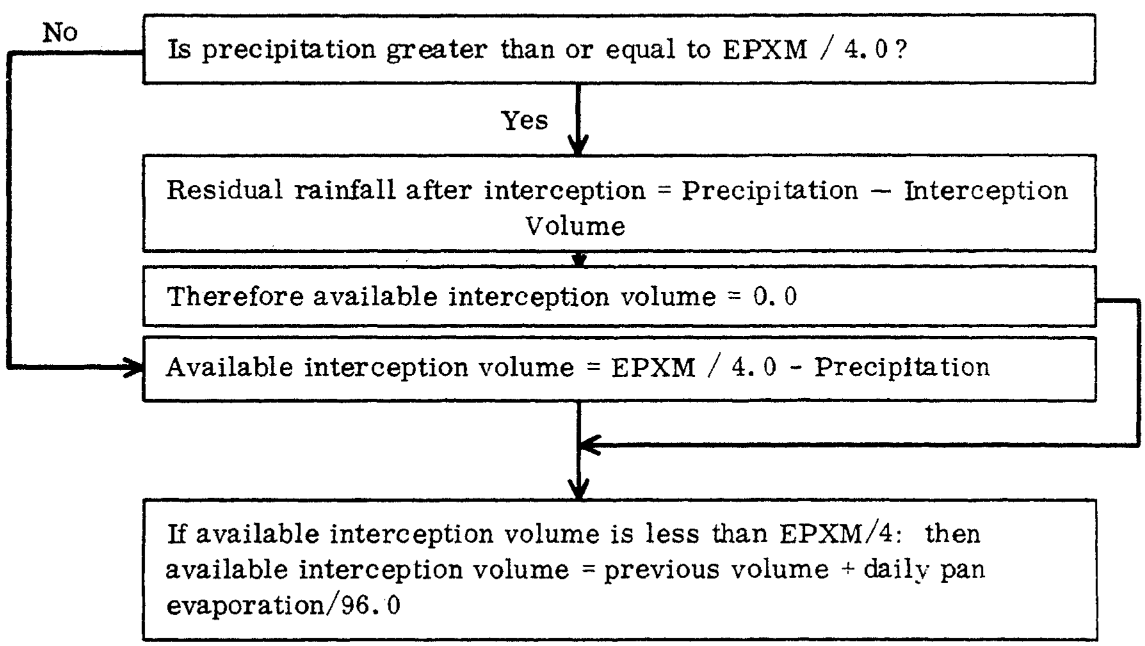
A general overview of the model's operation can be seen in the moisture accounting block diagram of Figure 3. The following material will be a step by step presentation of the model's components as outlined in the flow diagram.

For discussion purposes the hydrologic cycle will be subdivided into Land Surface and Channel System effects. Actual variable names employed in the computer program of the model will be used in this discussion.

LAND SURFACE EFFECTS

INTERCEPTION

Interception in any time interval is governed by watershed cover and by the current volume in interception storage. All incoming moisture enters interception storage until a preassigned volume is filled. The maximum preassigned interception volume EPXM, in inches per hour, is an input parameter. Following is an example procedure, based on 15 minute time intervals, of the model simulation of interception and its recovery of interception volume:



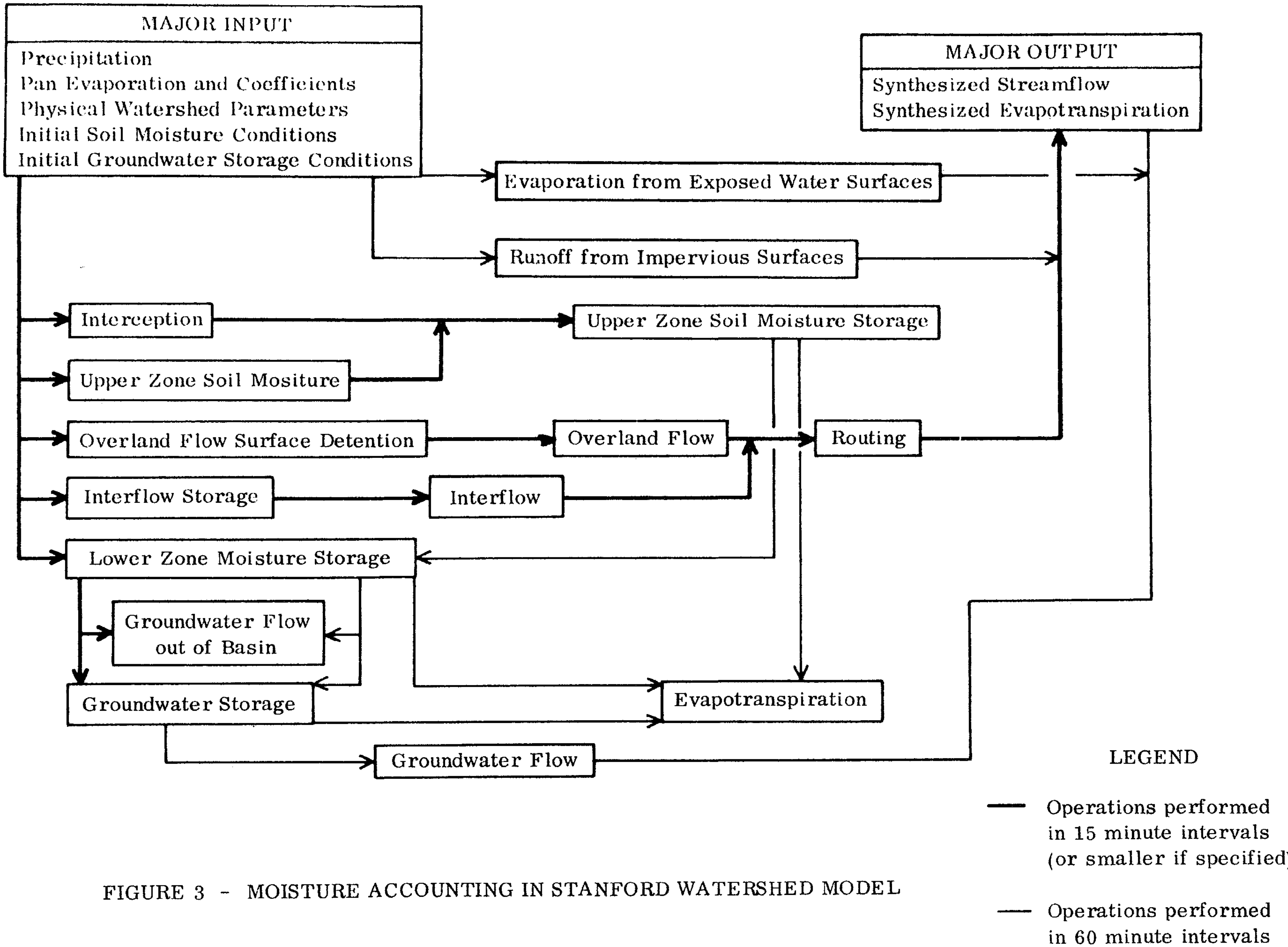


FIGURE 3 - MOISTURE ACCOUNTING IN STANFORD WATERSHED MODEL

The model simulates the recovery of interception storage volume at a rate equal to evaporation from a Class A pan until the limiting preassigned volume EPXM is satisfied. Thus, interception will continue during a storm dependent upon evaporation losses.

INFILTRATION

Direct Infiltration

The amount of rain water that enters the soil immediately following precipitation is known as direct infiltration. The concept of cumulative frequency distribution is used to solve the problem of areal variation in infiltration capacities. The basic concept is shown in Figure 4.

Functional relationships for land surface response are developed for all values of moisture supply $\overline{X}$, peak infiltration rate D4F, and interflow index C3. These functions give a piecewise smooth variation in model response as the moisture supply $\overline{X}$, varies. Figure 5 is an example of the distribution of component response as moisture supply is increased.

Before getting involved with presentation of the actual equations employed by the model and the program statement counterparts, let's define a methodology for presenting the material. The following is an example of the format that will be used.

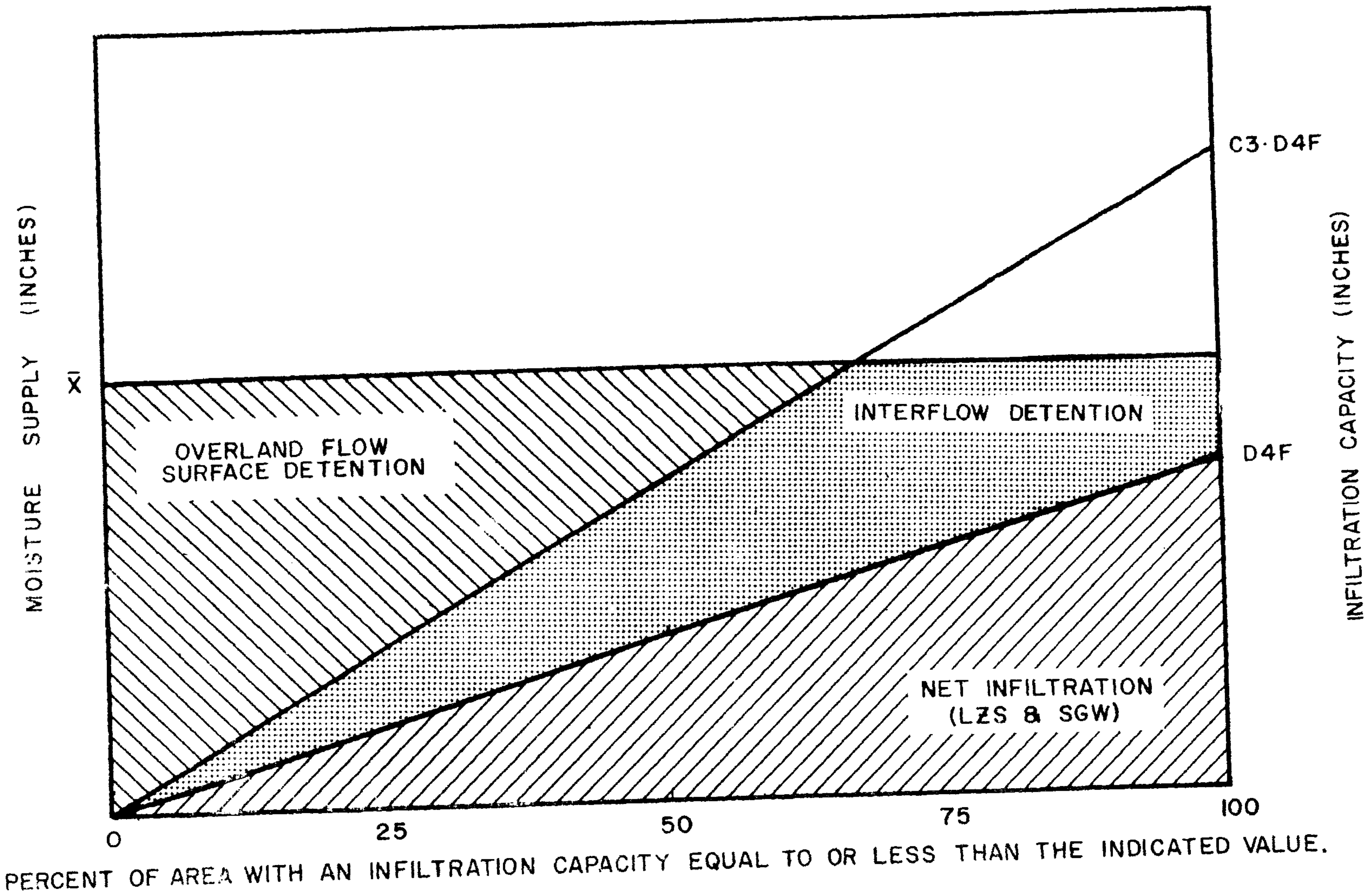


FIGURE 4. CONCEPT OF CUMULATIVE FREQUENCY DISTRIBUTION FOR INFILTRATION CAPACITY

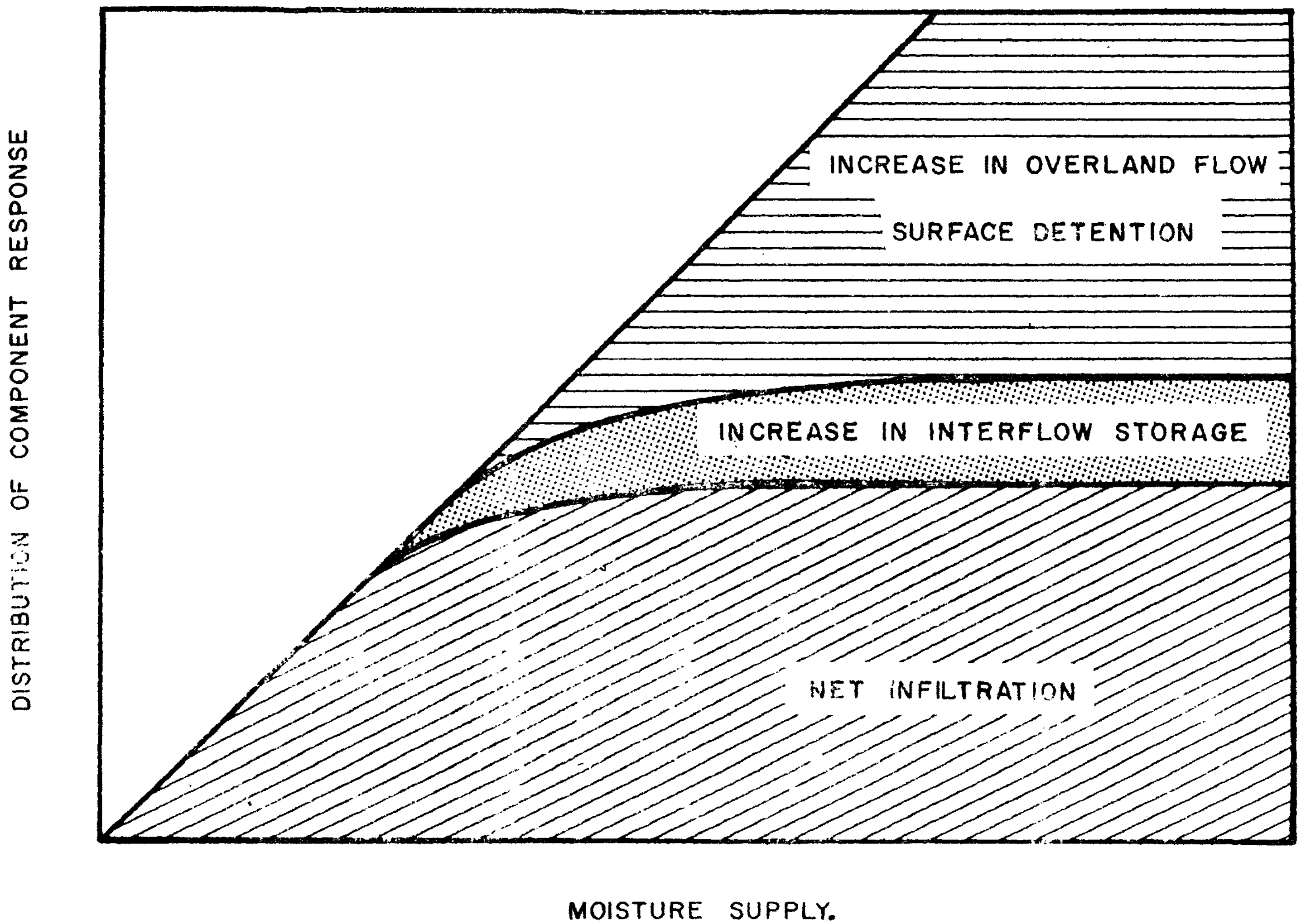


FIGURE 5. LAND SURFACE RESPONSE TO INCREASE IN MOISTURE SUPPLY

EXAMPLE FORMAT

X	X = Program Variable Identification Equation X = A + B . . . Number

A	Definition and formulation of variable A and all related variables.

B	Definition and formulation of variable B and all related variables.

The formulations for direct infiltration of the model are developed below:

D4F	D4F = Current peak infiltration rate D4F = FRAC * EN * C2 * CB / (2.0 ** LNRATM) . . . 3A

EN	EN = Factor varying infiltration by season EN = (SSEP/ISEP) ** EF SSEP = An evaporation parameter used to vary infiltration SSEP = 1.2 * ISEP --- Initial value SSEP = 0.96 * (SSEP + EP) --- As updated each day EP = Lake evaporation for current day EP = EVCR (FA) * E (I) EVCR = Monthly evaporation pan coefficient

FA = Current month of the water year

FA = Initialized, then incremented in program

E = Daily pan evaporation

E = Input data

I = Day of the year

I = Initialized, then incremented in program

ISEP = An evaporation parameter to vary infiltration

ISEP = (24/365) * AET

AET = Approximate annual lake evaporation

AET = AET + E (I)

AET = 0. 7 * AET

E = Explained above

I = Explained above

EF = Evaporation - Infiltration factor

EF = Input parameter

FRAC = Selected routing interval (TINC) expressed as fraction of an hour

FRAC = FLOAT (TINC) / 60

TINC = Selected routing interval

TINC = Input parameter

C2

C2 = Multiplier used in programmed adjustment of infiltration rate

C2 = C2 * (ALOG (DR)) / (ALOG (FLO))

DR = Synthesized average daily streamflow

FLO = Recorded average daily flow

FLO = Input data

CB

CB = Infiltration Index

CB = Input parameter

LNRATM

LNRATM = Soil moisture index used in estimating current infiltration rate

LNRATM = 4.0 * LNRAT when LNRAT is less than 1.0

LNRATM = 4.0 + 2.* (LNRAT - 1.0) when LNRAT is less than 2.0

LNRATM = 6.0 when LNRAT is greater than 2.0

LNRAT = Current ratio of soil moisture to soil moisture storage index

LNRAT = LZS / LZSN

LZS = Current soil moisture storage. The concept of LZS is shown in Figure 4

LZSN = Soil moisture storage index

LZSN = Input parameter

To properly understand the variation of D4F we must examine the seasonal variation of EN. For the Little Mill Creek (a test watershed which will be discussed in detail later) data several computer simulations were made with various values of EF. Figure 6 shows the seasonal variation of EN for various values of EF.

The variation of D4F with the LZS/LZSN ratio for winter and summer season, using Little Mill Creek data, and for variations in CB is shown in Figure 7.

Interflow Index

The treatment of interflow by the model is illustrated in Figure 4. The amount of interflow is assumed proportional to the infiltration capacity of an area. The interflow index is the variable which proportions the infiltration capacity into interflow. Following is the method by which the model treats the interflow index:

C3	C3	= Variable controlling entry of moisture into interflow	
	C3	= CY * 2.0 ** LNRAT	. . . 3B
CY	CY	= Interflow index	
	CY	= Input parameter	
LNRAT	LNRAT	= Current ratio of soil moisture storage to soil moisture storage index	
	LNRAT	= LZS/LZSN	
	LZS	= Previously defined - see equation 3A	
	LZSN	= Previously defined - see equation 3A	

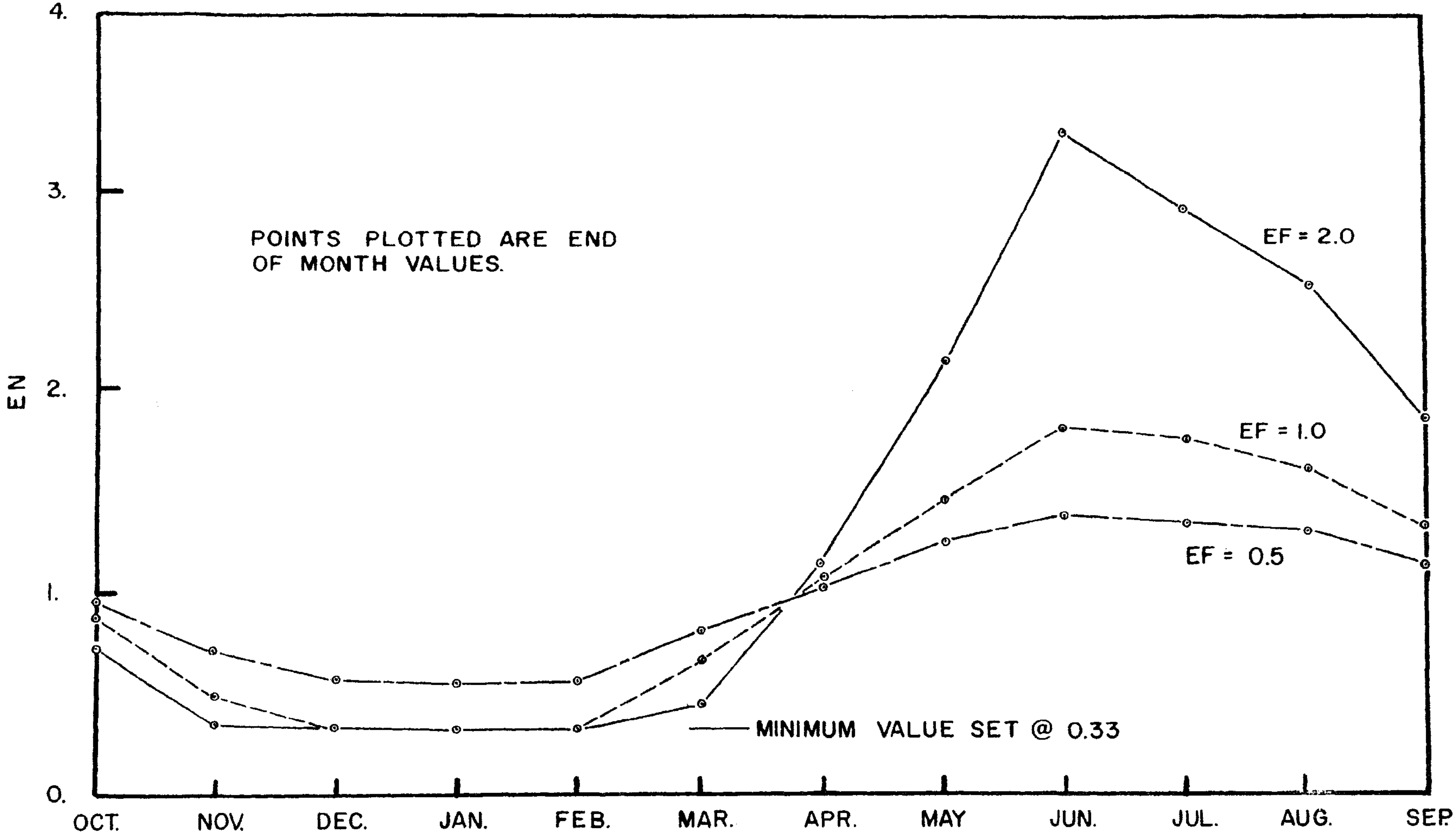


FIGURE 6. SEASONAL VARIATION OF EN FOR LITTLE MILL CREEK DATA

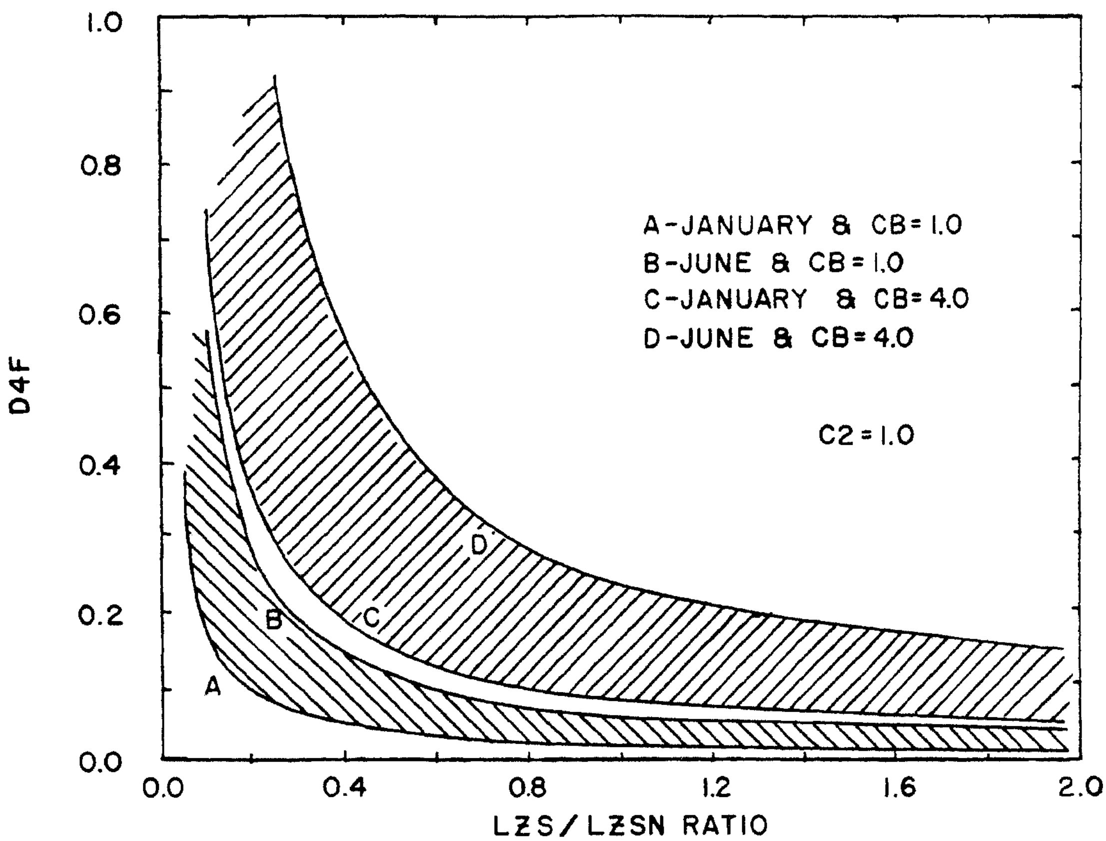


FIGURE 7. VARIATION OF INFILTRATION WITH THE LZS/ LZSN RATIO

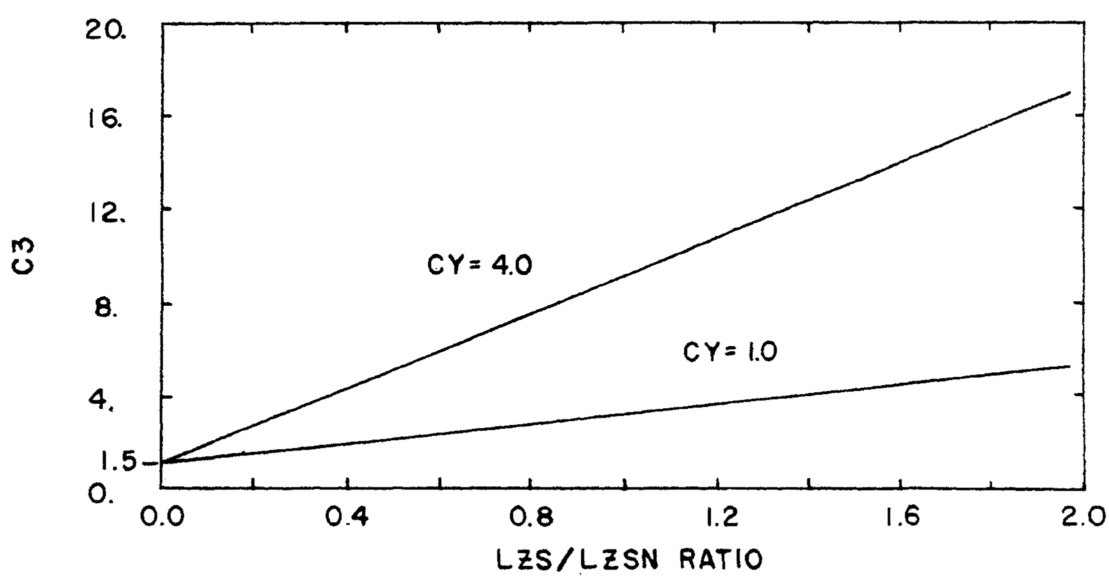


FIGURE 8. VARIATION OF INTERFLOW WITH THE LZS/ LZSN RATIO

The variation of C3 vs. the LZS/LZSN ratio for various values of CY is shown in Figure 8.

<u>Delayed Infiltration</u>

Direct infiltration starts at the beginning of rainfall. If the infiltration rate is less than the rainfall rate, the excess water becomes inflow to surface depressions. Before surface runoff can take place, depression storage must be satisfied. The amount of water from this temporary storage that infiltrates is handled as delayed infiltration by the model.

Depression storage, and storage in highly permeable surface soils are modeled by the upper zone. Moisture is lost from the upper zone by evapotranspiration and percolation to the lower zone and groundwater storage.

The following expressions develop the response of the upper zone to infiltration. The fraction of incoming moisture that is <u>not</u> retained by the upper zone is computed as follows:

PRE	PRE	= Fraction of incoming moisture that is <u>not</u> retained in upper zone storage
	PRE	= (1.0 / (1.0 + UZI)) ** UZI If UZS is less than UZSN, otherwise
	PRE	= 1.0 - PRE

UZI	UZI	= Intermediate soil surface moisture storage parameter for estimating depletion
	UZI	= 2.0 * ABS (UZS / UZSN - 1.0) + 1.0
	UZSN	= Soil surface moisture index

UZSN = EDF * SEP + CX * EXP (-2.7 LNRAT) + FACTOR

UZSN = 0.25 Minimum Preset Value

EDF = Index for estimating soil surface moisture storage

EDF = Input parameter

SEP = An evaporation parameter used to vary infiltration

SEP = 0.3 * ISEP -- Initial value

ISEP = An evaporation parameter used to vary infiltration -- see Equation 3A

SEP = 0.9 * (SEP + EP) -- Updated each day

EP = Lake evaporation for current day

EP = EVCR (FA) * E (I)

EVCR = Monthly evaporation pan coefficient

EVCR = Input data

FA = Current month of the water year

FA = Input data

E = Daily pan evaporation

E = Input data

I = Day of the year counter

CX = Index for estimating soil surface moisture storage

CX = Input parameter

FACTOR = (VOLUME * 12.0) / (AREA * 640.0)

VOLUME = Volume of water in acre feet allocated to swamp and soil crack storage

VOLUME = Input parameter

AREA = Basin area in square miles

AREA = Input parameter

LNRAT = See Equation 3B

LZS = Current soil moisture storage

LZS = See Equation 3A

LZSN = Soil Moisture storage index

LZSN = Input parameter

The above equations indicate the dependence of UZSN, upon potential evapotranspiration and the moisture stored in the lower zone.

The residual precipitation, after the upper zone storage requirements have been satisfied according to the above, is:

P4

P4 = Residual rainfall after soil surface moisture depletion

P4 = P3 * PRE . . . 3D

P3

P3 = Residual rainfall after interception depletion

P3 = PR - EPX

PR = Current rainfall rate

PR = Input data

EPX = Current interception rate

EPX = FRAC * EPXM

FRAC = The selected routing time increment (TINC) expressed as a decimal

EPXM = Maximum interception rate for a dry watershed

EPXM = Input parameter

PRE

PRE = Fraction of incoming moisture that is not retained in upper zone storage

PRE = See equation 3C

The value of moisture in the upper zone storage is maintained current by an updating process given by:

UZS

UZS = Current soil surface moisture storage

UZS = UZS + P3 - P4 . . . 3

P4 = Residual rainfall after soil surface moisture depletion

P4 = See equation 3D

P3 = Residual rainfall after interception depletion

Figure 9 shows the relationship of PRE and the UZS/UZSN ratio.

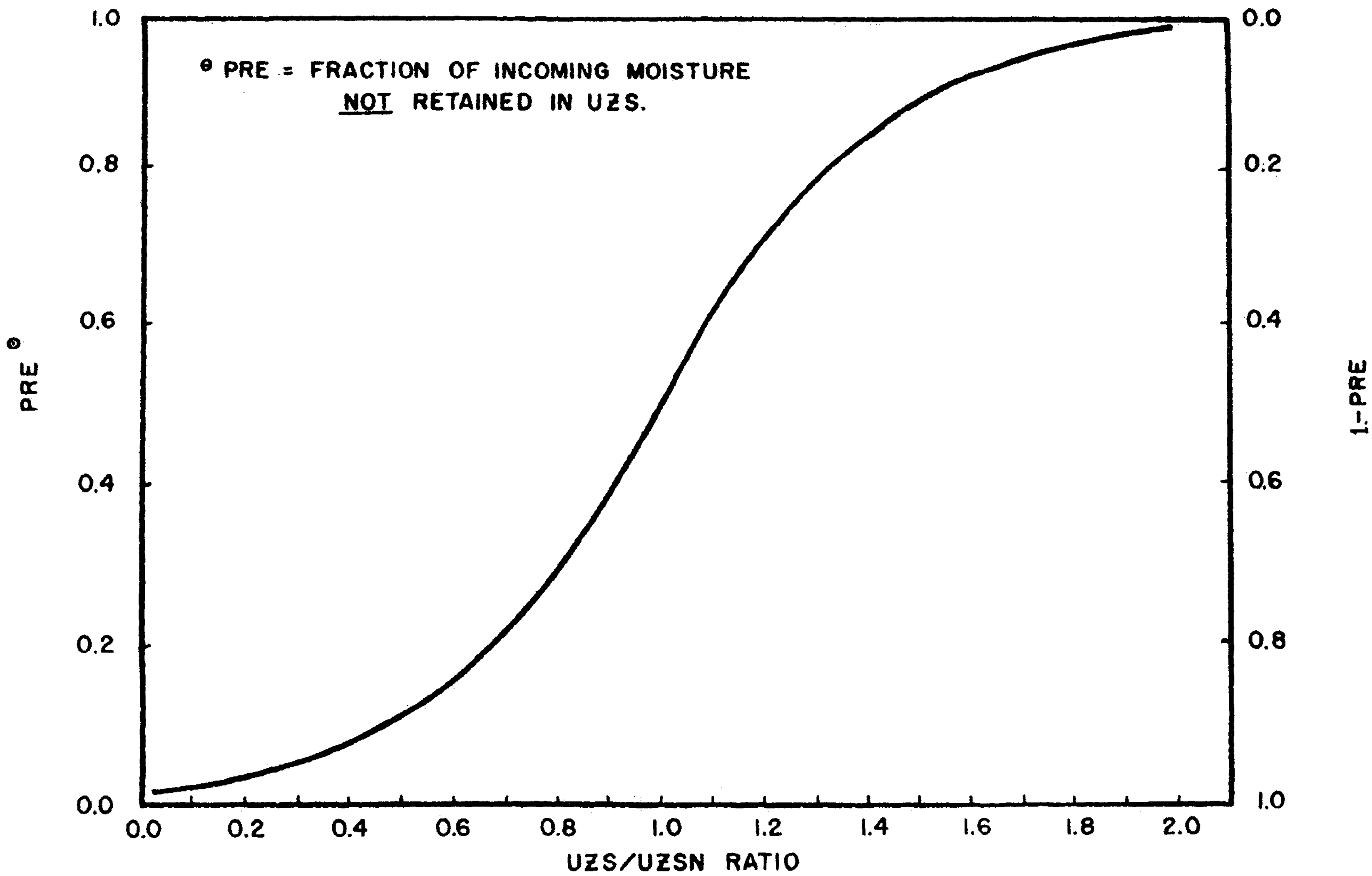


FIGURE 9. FRACTION OF INCOMING MOISTURE RETAINED IN UZS

Moisture is depleted from the upper zone storage by infiltration to the lower zone and by evapotranspiration at the potential rate. The current rate of infiltration from the upper zone, in inches per hour, is established as follows·

RECE	RECE	= Current rate of soil surface moisture infiltration
	RECE	= 0.003 * CB * UZSN * DEEPL ** 3.0 . . . 3F

CB	CB	= Infiltration Index
	CB	= See equation 3A

UZSN	UZSN	= Soil surface moisture index
	UZSN	= See equation 3C

DEEPL	DEEPL	= Index controlling infiltration rate of soil surface moisture
	DEEPL	= (UZS / UZSN) - (LZS / LZSN)
	UZS	= Current soil surface moisture storage
	UZS	= See equation 3E
	LZS	= Current soil moisture storage
	LZS	= See equation 3A
	LZSN	= Soil moisture storage index
	LZSN	= See equation 3C

The infiltrated moisture can now either be retained in the lower zone (soil between the water table and the land surface) or be passed in the groundwater region. The fraction of moisture that infiltrates from the upper zone and is retained in the lower zone is computed by:

PRE		
	PRE	= Fraction of incoming moisture retained in soil storage
	PRE	= (1.0 / (1.0 + LZI)) ** LZI . . . 3G

LZI		
	LZI	= Intermediate soil moisture parameter for estimating infiltration
	LZI	= 1.5 * ABS (LNRAT - 1.0) + 1.0
	LNRAT	= Current ratio of soil moisture storage to soil moisture storage index
	LNRAT	= LZS / LZSN - See equation 3B

The relationship of PRE to the ratio LZS/LZSN is shown in Figure 10.

The remaining infiltrated moisture can pursue two possible paths. One is to percolate into active groundwater storage within the basin to perhaps again reappear as streamflow or evapotranspiration. The other is to pass out of the basin as deep groundwater movement or go into deep groundwater storage never again to be considered in the model moisture balance.

OVERLAND FLOW

Turbulent range equations were used for development of the overland flow equations. The Chezy-Manning equation was used to derive a relationship

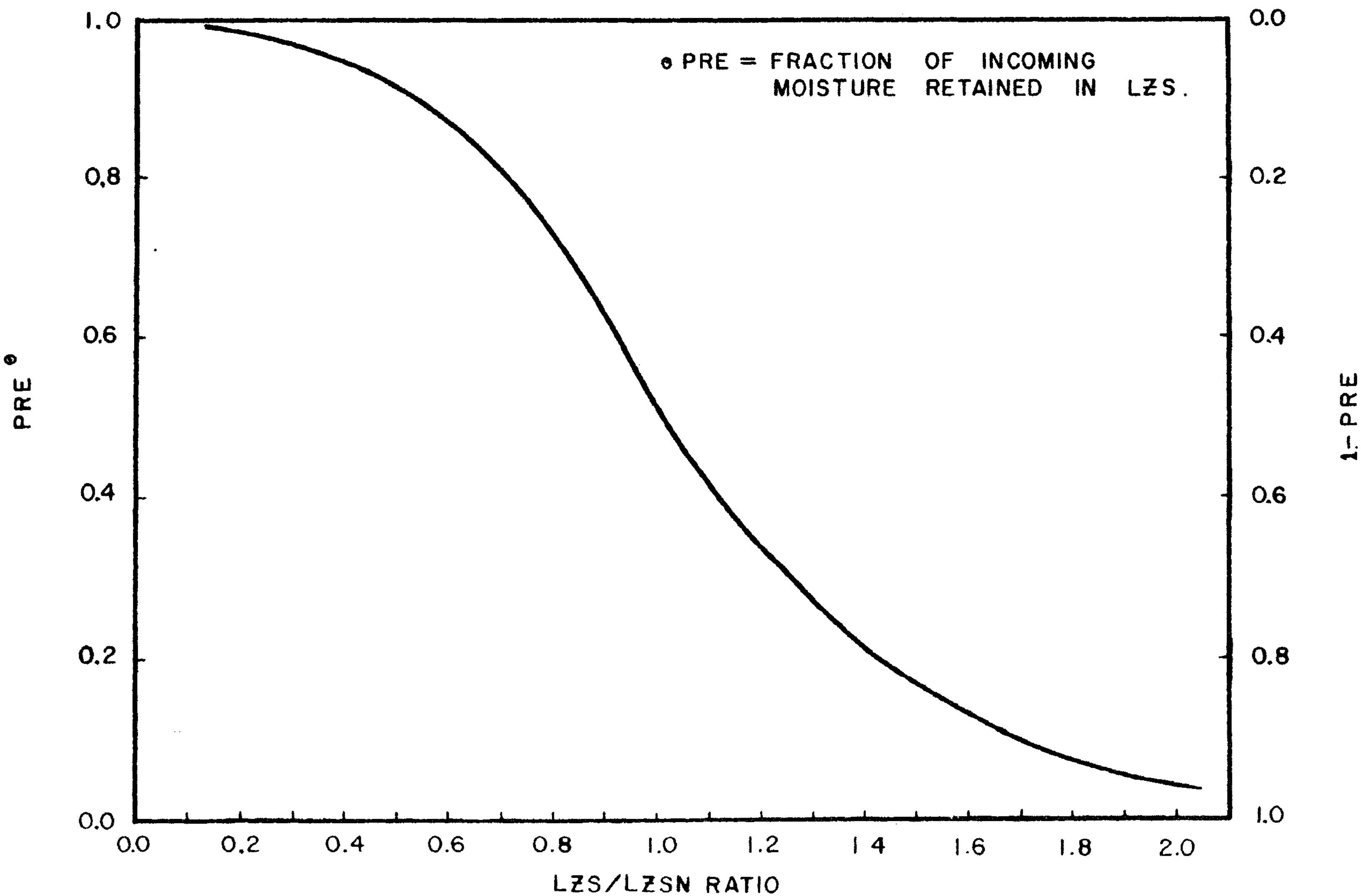


FIGURE 10. INFILTRATION FROM UZS THAT IS HELD IN LZS

between surface detention storage at equilibrium, the supply rate to overland flow, Manning's n, and the length and slope of the flow plane. The amount of surface detention at equilibrium is given as:

$$De = \frac{.00818 i^{0.6} n^{0.6} L^{1.6}}{S^{0.3}} \qquad \ldots 3H$$

where De is surface detention in ft.^{3}/ft., i is the supply rate in inches per hour, S is the slope in ft./ft., and L is the length of the overland flow in feet.

Based on the Manning equation the overland flow discharge is·

$$q = \frac{1.486}{n} y^{5/3} S^{1/2} \qquad \ldots 3I$$

for q in ft.^{3}/sec./ft., and where y is the depth in feet at the lower edge of the flow plane.

An empirical relationship developed by Crawford and Linsley between outflow depth and detention storage for reproducing experimental hydrographs is:

$$y = \frac{D}{L} \left[1.0 + 0.6 \left[\frac{D}{De} \right]^3 \right] \qquad \ldots 3J$$

where D = detention volume corresponding to y. By substituting equation 3J in equation 3I the rate of discharge from overland flow in ft.^{3}/sec. is:

$$q = \frac{1.486}{n} S^{1/2} \left[\left[\frac{D}{L} \right] \times \left[1.0 + 0.6 \left[\frac{D}{De} \right]^3 \right] \right]^{5/3} \qquad \ldots 3K$$

where De is a function of the current supply rate to overland flow and is computed from equation 3H.

The model continuously solves the continuity equation

$$D2 = D1 + \Delta D - \bar{q} \ \Delta t$$

where t is the time interval used, D2 is the surface detention at the end of the current time interval, D1 is the surface detention at the end of the previous time interval, ΔD is the increment added to surface detention in the time interval, and $\bar{q}$ is a function of the moisture supply rate and of (D1 + D2) / 2.0, the average detention storage during the time interval (D in equation 3K). The increment to overland flow surface detention, D, is found from equations based on Figure 4.

The model simulates overland flow from pervious and impervious surfaces with the same basic equations. The length, slope, and roughness coefficients are estimated for pervious and impervious surfaces and are used as input data in the watershed model.

INTERFLOW

The quantity of moisture inflow to interflow detention storage is illustrated by Figure 4. Outflow from this storage is computed by the logarithmic decay equation:

$$S_t = - \frac{q_t}{\ln K_r}$$

where S_t is the storage at time t, q_t is the flow at time t, and $\ln K_r$ is the natural logarithm of the interflow recession constant. The equation used in the model is:

INTF	INTF = Current rate at which interflow is entering the channel INTF = LIRC4 * SRGX . . . 3M

LIRC4	LIRC4	= Natural logarithm of IRC4
	IRC4	= IRC ** (1.0 / (24.0 * 60.0/FLOAT (TINC)))
	IRC	= Daily interflow recession constant
	IRC	= Input parameter
	TINC	= Selected routing interval
	TINC	= Input parameter

SRGX	SRGX	= Current volume of water in interflow storage
	SRGX	= SRGX + RGX * PA
	RGX	= Water entering interflow storage
	RGX	= SHRD - RX
	SHRD	= Sum of current moisture entering surface runoff plus interflow
	SHRD	= P4 * P4 / (2.0 * D4F)
	P4	= Residual rainfall after soil surface moisture depletion
	P4	= See equation 3D
	D4F	= Current peak infiltration rate
	D4F	= See equation 3A
	RX	= Current direct runoff
	PA	= Pervious fraction of watershed
	PA	= Input data
	RX	= P4 * P4 / (2.0 * D4F * C3)
	P4	= See equation 3D

D4F	= See equation 3A
C3	= Variable controlling entry of moisture into interflow
C3	= See equation 3B

GROUNDWATER FLOW

The inflow to groundwater storage consists of a portion of the net infiltration (shown in Figure 4) and a portion of the delayed infiltration from the upper zone storage. The fraction of either direct or delayed infiltration that enters the groundwater storage is a function of the dimensionless ratio LZS/LZSN.

The relationships for the fraction of moisture that infiltrates from the upper zone moisture storage to the lower zone moisture storage and is retained in the lower zone have been discussed previously and are shown in Figure 10. The relationships for the fraction of moisture that percolates to groundwater from the lower zone are read on the right hand ordinate in Figure 10.

The outflow from groundwater storage may be distributed to baseflow in the stream and to satisfy evapotranspiration, if it exists, from phreatophytes. Base flow from groundwater is modeled by the logarithmic decay equation

$$S_t = - \frac{q_t}{\ln K_r}$$

where the terms of the equation are the same as those of equation 3M, with a modification which permits increased groundwater flow to reflect changes in the recession constant due to wet antecedent conditions.

The equation used by the model for groundwater flow to the stream is·

GWF	
GWF	= Baseflow
GWF	= SGW * LKK4 * (1.0 + LKV4 * GWS) . . . 3N

SGW	
SGW	= Groundwater moisture storage
SGW	= SGW + F1
F1	= Infiltration reaching groundwater
F1	= (1.0 - PRE) * (P4 - SHRD) * (1.0 - K24L) * PA for infiltration reaching groundwater from the lower zone storage
PRE	= Fraction of incoming moisture retained in soil surface or soil storage
PRE	= See equation 3G
P4	= Residual rainfall after soil surface moisture depletion
P4	= See equation 3D
SHRD	= Sum of current moisture entering surface runoff plus interflows
SHRD	= See equation 3M
K24L	= Parameter indicating groundwater flow leaving the basin
K24L	= Input parameter
PA	= Pervious fraction of the watershed
PA	= Input data
F1	= (1.0 - PRE) * RECE * (1.0 - K24L) * PA for infiltration reaching groundwater from the upper zone

PRE = Fraction of incoming moisture retained in soil surface or soil storage

PRE = See equation 3C

RECE = Current rate of soil surface moisture infiltration

RECE = See equation 3F

(All other terms are common to both equations for F1)

LKK4

LKK4 = Natural logarithm of KK4

KK4 = Hourly base flow recession constant

KK4 = KK24 ** (1.0/24.0)

KK24 = Daily base flow recession constant

KK24 = Input parameter

LKV4

LKV4 = Natural logarithm of KV4

KV4 = Hourly base flow recession adjustment factor

KV4 = KV24 ** (1.0/24.0)

KV24 = Daily base flow recession adjustment factor

KV24 = Input parameter

GWS

GWS = Current value of groundwater slope index

GWS = GWS + F1

F1 = Infiltration water reaching groundwater

F1 = See equation 3N

The term (1.0 + LKV4 * GWS) of equation 3N is a modification to the basic logarithmic depletion curve. The variable GWS is termed groundwater slope and is actually an antecedent precipitation index. GWS is increased as shown in Equation 3N and depleted daily by the equation:

GWS = 0.97 * GWS

with a minimum preset value of 0.0. Figure 11 shows the relationship of the percent increase in groundwater flow vs. KV24 for various values of GWS.

Percolation to deep, inactive, or groundwater flow out of the basin is modeled by allowing a fixed portion of inflow to groundwater storage to bypass the active storage that contributes to streamflow and evapotranspiration. This fraction is controlled by the variable K24L and is shown in Equation 3N.

Groundwater loss to evapotranspiration is governed by the following equation:

LOS	LOS = Groundwater Evaporation	
	LOS = SGW * K24EL * EP * PA	. . . 3O

SGW	SGW = Groundwater moisture storage
	SGW = See equation 3N

K24EL	K24EL = Groundwater evaporation parameter
	K24EL = Input parameter

EP	EP = Lake evaporation during day being analyzed
	EP = See equation 3C

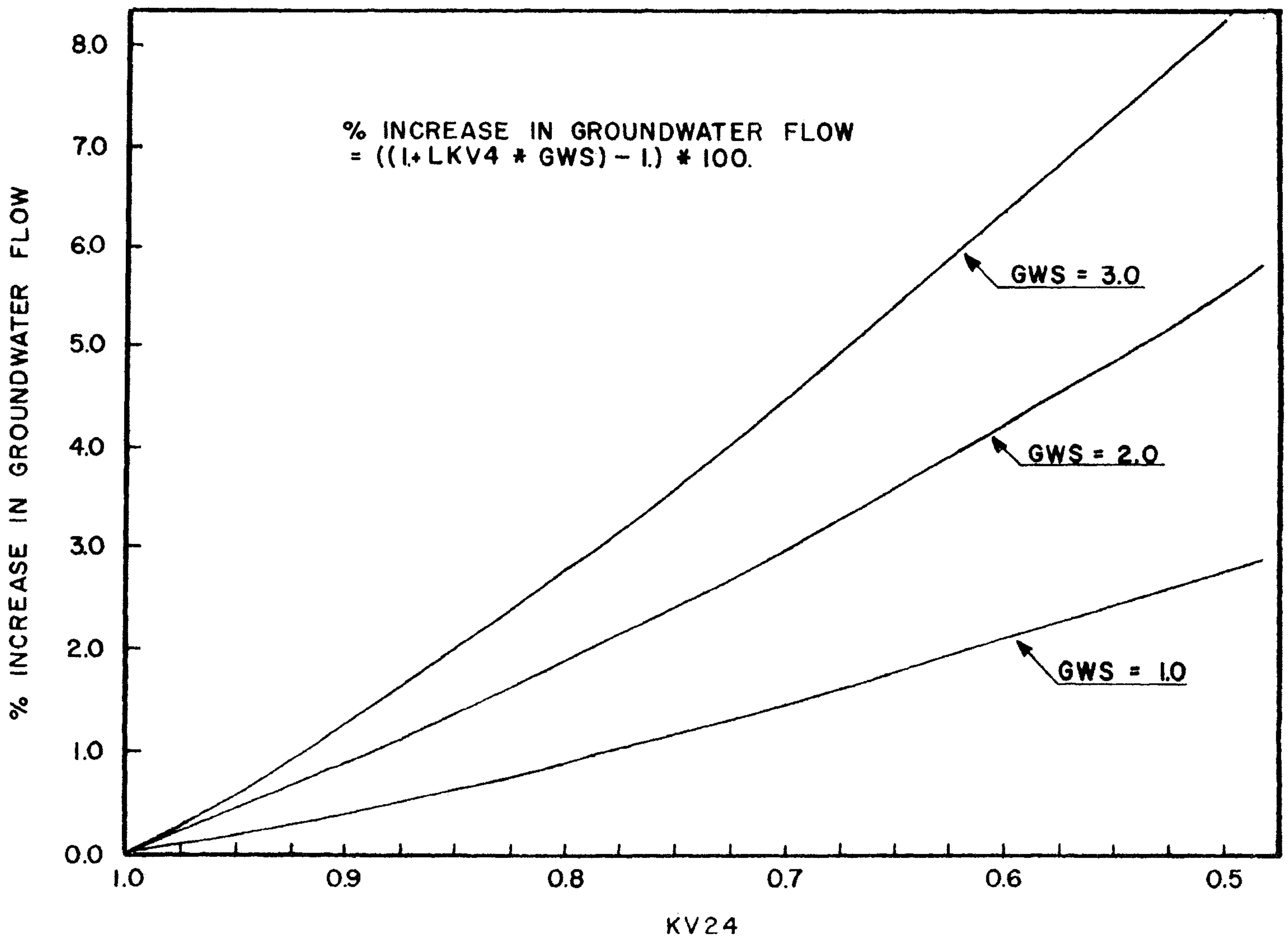


FIGURE 11. EFFECT OF BASE FLOW RECESSION CONSTANT ADJUSTMENT FACTOR ON BASE FLOW

PA	PA = Pervious fraction of watershed surface
	PA = See equation 3N

These equations show that the groundwater loss is modeled at a rate dependent on potential evapotranspiration.

EVAPOTRANSPIRATION

Evapotranspiration is simulated from four moisture sources. It occurs from the upper zone storage, exposed water surfaces, and goundwater storage at the potential rate and from the lower zone storage at the opportunity rate. Potential evapotranspiration is assumed to be equal to lake evaporation estimated from U. S. Weather Bureau Class A pans.

The model first attempts to satisfy the potential from the upper zone soil moisture storage. Any remaining potential, entered as EP in Figure 12, is supplied from the lower zone moisture storage at the opportunity rate.

The formulation for Figure 12 is:

$$r = K3 * LZS/LZSN$$

(terms of equation are defined in the following text)

Evapotranspiration from the lower zone moisture storage is given as·

AETR	AETR = Synthesized daily evaporation from the soil (if EP is less than r)
	AETR = EP * (1.0 - EP/2.0 * K3 * LNRAT) . . . 3P

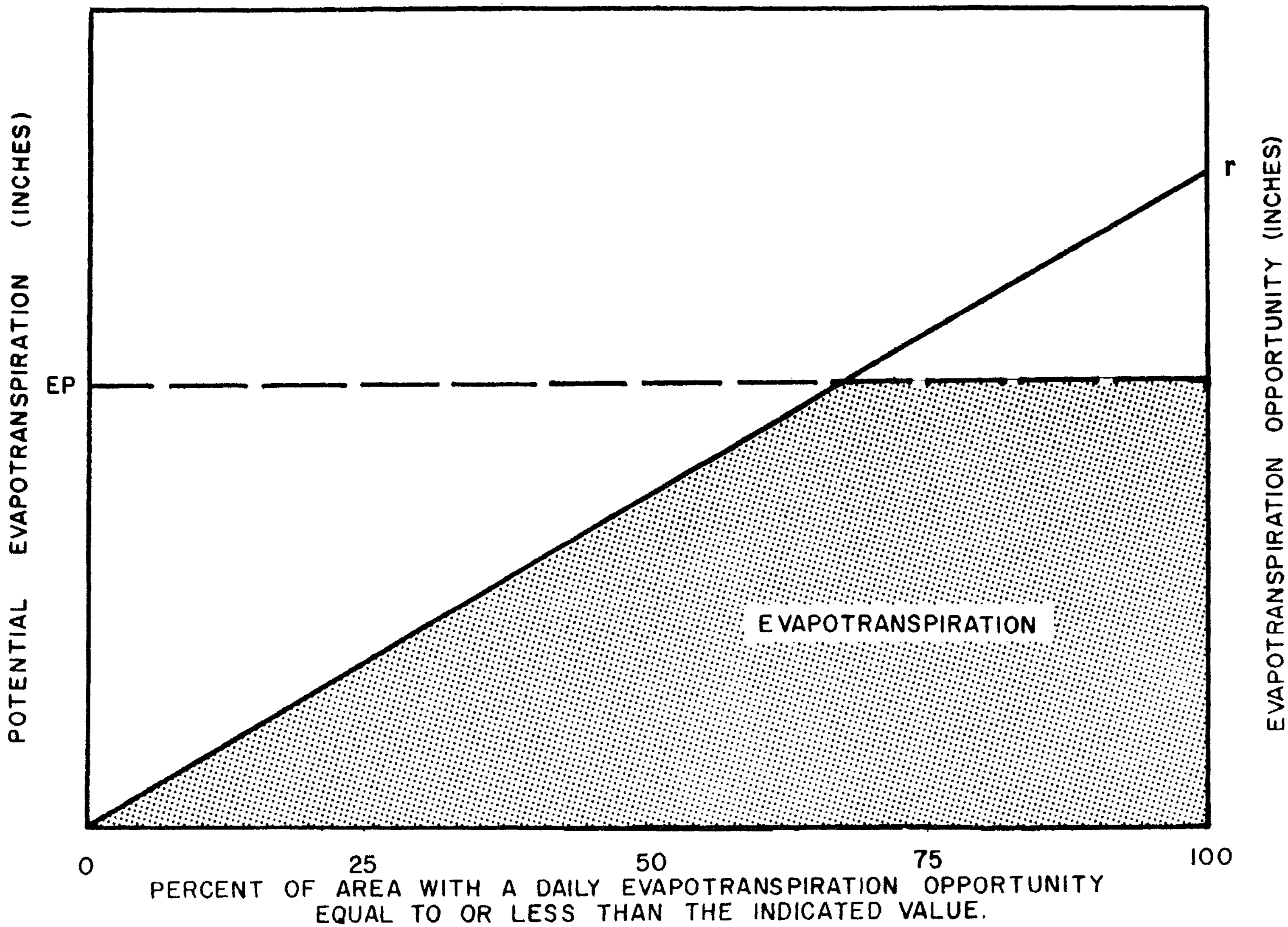


FIGURE 12. EVAPOTRANSPIRATION OPPORTUNITY FROM LZS

EP	EP = Lake evaporation during day being analyzed EP = See equation 3A

K3	K3 = Soil evaporation parameter K3 = Input parameter

LZS	LZS = Current soil moisture storage LZS = See equation 3A

LZSN	LZSN = Soil moisture storage index LZSN = See equation 3A

AETR	AETR = Synthesized daily evaporation from soil (if EP is greater than r) AETR = (K3 * LNRAT) / 2.0 . . . 3P-1 All terms defined above

Evapotranspiration from exposed stream surfaces is modeled to occur between 9 A. M. and 9 P. M. daily in accordance with the following critique:

ELH	ELH = Watershed evaporation from exposed water surfaces ELH = (ETL * EP) / 12.0 . . . 3Q

ETL	ETL	= Fraction of total watershed in stream surface
	ETL	= Input parameter

EP	EP	= Lake evaporation during day being analyzed
	EP	= See equation 3C

If ELH is greater than the groundwater flow, ELH is set equal to the groundwater flow.

Evapotranspiration from groundwater storage is in accordance with the following equation which was explained as equation 3O.

$$LOS = SGW * K24\ EL * EP * PA$$

SNOWMELT

The original version of the Stanford Watershed Model IV contained an adequate snowmelt subroutine which performed the melting processes of snow quite well. This subroutine, however, required detailed snow survey data which is not available in regions where snow is a minor contributor to annual precipitation. For example, when there is some question as to whether the precipitation input is rain or snow the subroutine would check the calculated depth of snow to the actual depth obtained by snow surveys. In the Midwest, such as Ohio, this type of information is not available. Unlike the Western United States, for which the original subroutine was developed, the winters in Ohio are mild and the volume of snow, approximately 5 percent of the precipitation, which accumulates during the winter months does not warrant the meteorological stations to take extensive snow survey data. Therefore, the Model IV snowmelt subroutine, which was written for large snow inputs, could not be used for studies with Ohio data. Consequently an entirely new snowmelt subroutine was created for watersheds having small inputs of snow. Streamflow simulation models, to be applicable in areas of snowfall, must properly predict both the timing and the quantity of melt.

Knowing the density of fallen snow is a significant factor in determining the timing of the snowmelt. Usually freshly fallen snow has a density ranging from 5 to 15 percent of that of its liquid state, rain.

The density can vary with such factors as temperature, wind, and compaction. Denser snows make it more difficult for the meltwater to percolate through the snow to the ground. To ascertain a reasonably accurate value for the density it is required to know the length of time the snow lies on the ground. The metamorphosis is called the ageing of snow. If all snows were to melt within several days after falling there would not be any major ageing problem to contend with; however, melt may not occur for a few months. Therefore, additional snows will accumulate on top of the original and cause it to compact. This may increase the density even to as high as 35 percent.

Snowmelting is a very complex process. If the temperature since the last snow has been oontinually below 32°F then the temperature of the snowpack will normally be less than 32°F. Eventually, when the weather begins to warm up, the pack will begin to melt at the exposed surface due to contact with the warm air, condensation of water vapor, and absorption of radiation. This meltwater percolates into the remaining snow, but it is quickly refrozen because of the temperature of the snowpack. The refreezing water releases its latent heat of fusion within the snowpack and warms it up slightly. Working simultaneously with this melting process is conduction from the ground and the warming of the snow surface. These three mechanisms continue to warm the snow until the temperature of the pack is raised to $32^{o}F$.

At this point any more melting snow will not refreeze. As the melting processes continue water begins to accumulate within the snowpack until the channels between the ice crystals are full. Under this condition the pack can no longer assimilate any more meltwater. This is known as the liquid-water-holding-capacity of the snowpack and designates that the pack is "ripe" (ready to release water). But the liquid-water-holding capacity of the snow is variable and will depend upon the condition of the pack. It is a function of the density, extent of ice lenses, and the size, shape, and spacing of the snow crystals. These factors should also be evaluated if an accurate holding-capacity of the snow is needed. Any melt which occurs after the water capacity is reached will percolate through the snowpack and drain into or onto the ground. Naturally, this will continue until the snowpack has been depleted or until the warm weather has subsided.

Following is a summary of the methods of melting snow. It should be noted that most of the methods are simply heat balance equations of pure physics but a few contain empirical coefficients which have been determined by experimentation coordinated with heat transfer theory.

Not only must the quantities of melt be known for an accurate simulation but also the processes which cause them. There are five aspects of the melting phenomenon which should be evaluated to determine the quantities of snowmelt; and a sixth one which does not add to melt runoff but helps to deplete the snowpack.

Melt Due to Rainfall

When precipitation in the form of rain occurs while there is snow on the ground it must produce melt by obeying the laws of physics.

The melt can be expressed by:

$$M = \frac{PX\ (TEMP-32)}{(144)\ QT}$$

where:

PX = Depth of rain in inches,

TEMP = Wet bulb temperature which can be assumed to the the temperature of the rain in degrees F.,

QT = Thermal quality of the snow,

M = Amount of melt in inches of water.

The meaning of the formula is that one inch-degree of rain will cause 1/144 inch of snowmelt. This is because 1 pound of water will give up 1 BTU of heat when cooled, but it would take 144 BTU to melt 1 pound of ice. The thermal quality of the snow, which is the decimal fraction of its total weight that is in the form of ice, is multiplied by 144 to find the number of BTU needed to melt 1 pound of snow. Usually, the thermal quality ranges from 0.85 to 0.95.

Melt By Radiation

Radiation is one of the most important factors in melting snow because it is uaually the major contributor. In determining the melt both longwave and shortwave radiation should be considered. Shortwave radiation is received directly from the sun in amounts dependent upon the albedo (the portion of incoming radiation that is reflected by the snow) of the snow surface and vegetative interception. Longwave radiation is that resulting from a radiation exchange between the snow and the surroundings. It is affected by several factors; cloud coverage, canopy extent, temperature, and the type of environment. Both types of radiation can be evaluated with the same formula except that longwave radiation can be negative and will therefore result in heat lost from the snowpack.

The melt due to radiation can be determined by:

$$M = \frac{ALANG}{(203.2)\ QT}$$

where:

ALANG = Net absorbed radiation in langleys,

QT = Thermal quality of the snowpack,

M = Melt in inches of water.

The number 203.2 is a factor which converts langleys to inches of water (203.2 langleys/inch) when the pack is in the form of ice. Hence, QT is multiplied by 203.2 to determine the amount of langleys/inch needed to melt the snowpack that has a thermal quality less than 100 percent.

Melt Due to Conduction

Conduction is usually considered negligible in determining snowmelt. Normally, the temperature of the ground will increase with the depth of the soil. This causes a continual flow of heat toward the snowpack at the ground surface. Although melt produced by conduction is rather small a few days after the snow has fallen it can aid in keeping the soil moist so that quicker streamflow responses can occur when melt is produced by other means.

Conduction melt can be expressed by:

$$M = K$$

where:

K = A constant value of melt in inches per day,

M = Melt in inches per day.

The value of K ranges from 0.00 to 0.02 and can be a significant factor in adding to soil moisture during the winter months.

Melt Due to Convection

As air blows over the snow it transfers heat to the snowpack. The amount of heat depends upon the difference in temperature between the air and snow, and the speed of the moving air.

The formula can be expressed by·

$$M = \frac{(COE)\ (VW)\ (TEMP-32.)}{QT}$$

where:

COE = A coefficient based on the turbulent heat flow transfer theory,

VW = Velocity of the wind in mph,

TEMP = Temperature of the air at the snow surface in degrees F.,

QT = Thermal quality of the snow,

M = Melt in inches per 6 hours.

The value of COE may be represented by the quantity (0.00184 x $10^{-0.0000156h}$), where the portion $10^{-0.0000156h}$ represents the change of the barometric pressure due to a change in the elevation, h. These values are for an open field that does not have any obstructions to the wind. Due to the fact that most watersheds will have some trees and hills the actual value of COE will be slightly lower than the theoretical value.

Snowmelt By Condensation

Condensation can also be a major input to the melting of snow. The quantity of available moisture in the air and the rate with which fresh air is brought into contact with the snow surface will determine the amount of snowmelt.

The formula can be expressed by:

$$M = \frac{(B)\ (VW)}{QT}\ (VAPRES - 6.11)$$

where:

B = An empirical constant,

VW = Velocity of the wind in mph,

QT = Thermal quality of the snowpack,

VAPRES = Vapor pressure of the air in millibars (mb),

6.11 = Saturation vapor pressure in mb over ice at 32°F,

M = Melt in inches per 6 hours

After determining the amount of melt caused by vapor condensation on the snowpack the actual amount of condensate must also be added to the pack. Because 144 BTU are needed to melt 1 pound of ice at 32°F and 1073 BTU are given up when 1 pound of moisture is produced by condensation from vapor at 32°F, one inch of vapor condensation will produce $(\frac{1073}{144})$ 7.5 inches of snowmelt. Therefore, the amount of snowmelt from condensation should be multiplied by 1/7.5 and added to the snowpack.

Loss From Snowpack Due to Evaporation

When the dewpoint temperature is less than 32°F sublimation, rather than condensation, will occur. As with condensation, evaporation is a function of wind speed and the difference in vapor pressure between the air and the snow.

The formula can be expressed by:

$$E = \frac{(BPRI)\quad(VW)}{QT}\ (VAPRES - e_s)$$

where:

BPRI = An empirical constant,

VW = Wind speed in mph,

QT = Thermal quality of the snowpack,

VAPRES = Vapor pressure of the air in mb,

e_s = Saturation vapor pressure over the snow,

E = The evaporation from the snowpack in inches of water.

Evaporation is a direct loss from the snowpack but should be considered to maintain a water balance within the basin.

Also, evaporation loss through interception of the snow is a factor to be considered. Snow Hydrology (1956) shows that these losses are directly proportional to the forest cover density.

The formula can be expressed by:

$$I = KCP$$

where:

K = Interception loss with 100 percent cover density,

C = Fraction of net forest cover,

P = Snowfall in inches,

I = Interception loss in inches of water.

Experiments of snow evaporation losses have also been performed by Satterlund and Haupt (1970). Their findings indicate that more than 80 percent of the snow initially caught by conifers eventually reached the ground by rain, direct mass release, or melting. Evaporation losses represented only a small portion of the precipitation. Therefore, interception losses can be considered minor when compared to the overall problem.

The above six factors, along with precipitation, combine to account for the additions and losses to the snowpack; and if proper data is used should result in a reasonably accurate balance between snow, rain, melt, and runoff.

A block diagram of the snowmelt subroutine is shown if Figure 13.

Definition of Snowmelt Variables

The program variables and their definitions are shown in Table 1.

Rain or Snow Test

The temperature is the most important criteria for determining whether the precipitation is rain or snow. For this reason a detailed study was made on the existing data in order to find a more suitable temperature cutoff between snow and rain; or to verify the standard cutoff at 32^{o}F.

The temperature range (minimum to maximum) was graphed, for records of precipitation occurring as snow, against a particular month for 5 continuous years of data. The results, based on observations, conclude that 32^{o}F is not the best cutoff temperature between rain and snow for each month of the winter; and it was found that the cutoff values are different for at least four of the five months of the snow season. Example results for a test watershed (W/S 97 Coshocton) in Ohio are summarized in Table 2. It should be noted that these values do not necessarily represent all locations in Ohio. Therefore, a similar analysis will have to be made each time the model is used on a different watershed.

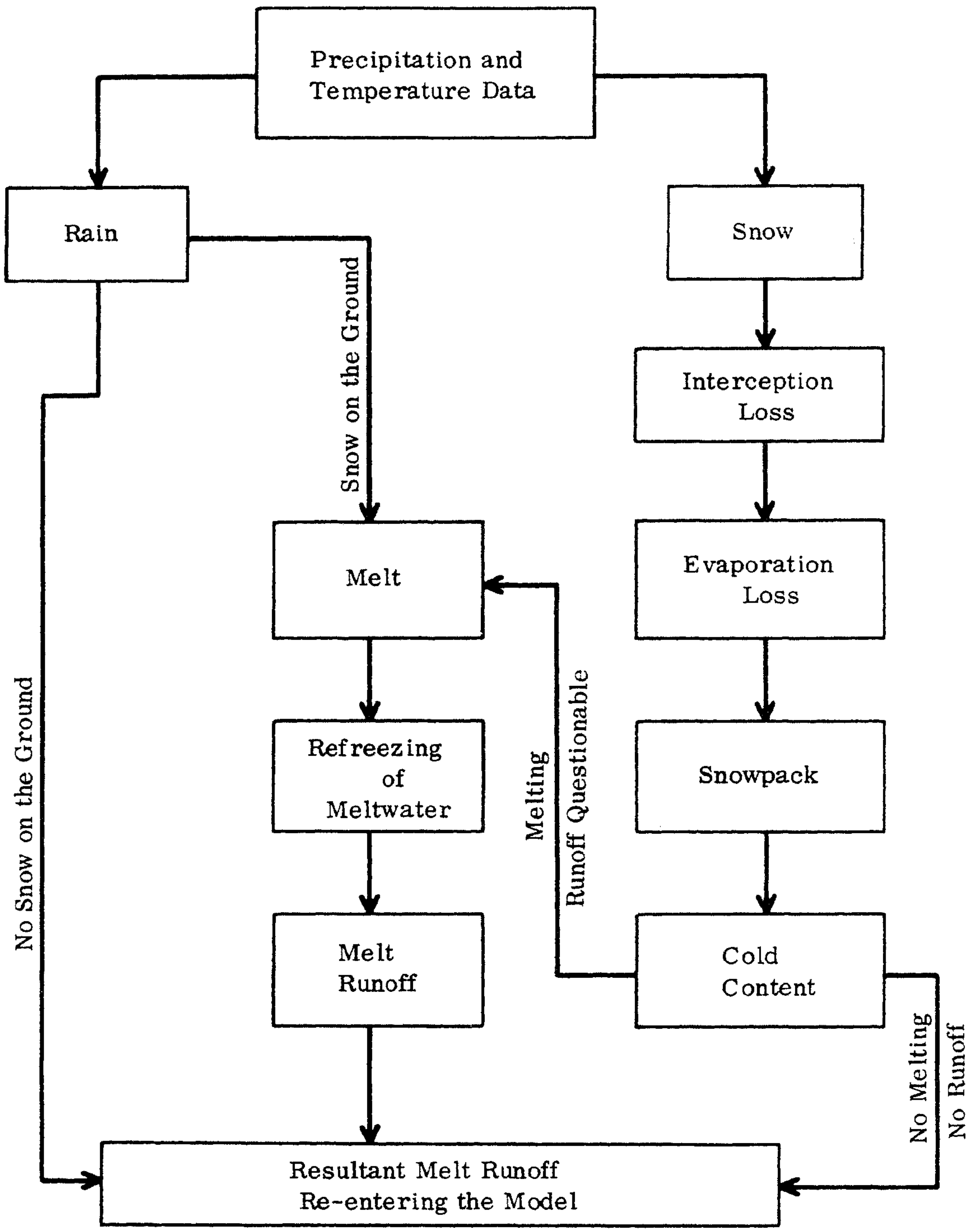


FIGURE 13. BLOCK DIAGRAM OF THE SNOWMELT SUBROUTINE

Table 1. Dictionary of Snowmelt Variables

Variable	Units	Definition
ALANG*	Langleys/day	Total solar radiation per day
ALNG	Langleys/hr.	Total absorbed radiation per hour
B*	---	Empirical constant for condensation
BPRI*	---	Empirical constant for evaporation
CDM	in.	Condensation melt
COE*	---	Empirical constant for convection
CVM	in.	Convection melt
DEN	---	Snow density
DEPTH	in.	Average depth of snow on the ground
ELDIF*	1000 ft.	Elevation difference between base thermometer and mean elevation of drainage basin
F*	---	Fraction of the total watershed in forest
GM*	in.	Conduction melt (ground)
IFACTR	in/hr/^{o}day	Basic snowmelt rate
IPACK*	in.	Minimum snowpack water at which entire basin is covered with snow
ITI*	in.	Index precipitation for changing snow albedo
KINT*	---	Fraction of snow falling on forest intercepted by trees
LIQS*	in.	Liquid-water-holding capacity of the snow
LIQW	in.	Liquid water content of the snow
MAXRAT*	in/^{o}F/hr	Rate of Cold Content build-up within the snowpack
NEGMEL	in.	Amount of cold content within the snowpack
PACK	in.	Water equivalent of the snowpack
PX	in.	Amount of melt runoff
QT	---	Thermal quality of the snowpack
QTI*	---	The initial thermal quality of freshly fallen snow
RADM	in.	Radiation melt
RATE	in/hr	The incremental cold content addition to the snowpack
RM	in.	Melt due to rain
SCF*	---	Snow correction factor

* input variable

Table 1, continued

Variable	Units	Definition
SDEN	---	Current snowpack density
SMELT	in.	Total amount of melt from the snowpack
SPXI	in.	Annual snowfall moisture
SPX2	in.	Annual snowfall moisture reaching the ground
TI	^oF	Average 4 a.m. temperature over the watershed
T2	^oF	Average 4 p.m. temperature over the watershed
TDEW*	^oF	5 degree temperature increments corresponding to known vapor pressures
TDPT	^oF	Average daily dewpoint temperatures
TEMP	^oF	Hourly calculated temperatures over the watershed
TIMNDX	---	Snow albedo index
TMAX*	^oF	Maximum recorded temperature during the day
TMIN*	^oF	Minimum recorded temperature during the day
TQT	---	The hourly stored thermal quality of the snow
VAP*	mb.	Vapor pressure increments corresponding to known temperatures
VAPRES	mb.	Average vapor pressure over the watershed per hour
VW*	mpd	Average daily wind movement
VWIND	mph	Average hourly wind movement
WC*	---	Water content of the snow at saturation
ZCDM	in.	Hourly values of melt from condensation
ZCVM	in.	Hourly values of melt from convection
ZLQW	in.	Hourly values of the liquid water content
ZPCK	in.	Hourly values of the water equivalent of the snowpack
ZPX	in.	Hourly values of the snowmelt runoff
ZRADM	in.	Hourly values of the melt from radiation
ZRM	in.	Hourly values of the melt from rainfall
ZTMP	^oF	Average temperature on the watershed per hour
ZYSNOT	in.	Stores the amount of precipitation that is simulated as snow

* input parameters

This, however, does not present any major difficulty because the data may be analyzed in a very short time.

By using the Table 2 values, for the location under study, to separate the precipitation into rain or snow, a more accurate simulation of snowfall was possible.

Criteria for Zero Melt

In making the first trial runs with the snowmelt subroutine it was evident that computed melt, during periods of moderately freezing temperatures, was substantial enough to increase runoff even though the recorded streamflows had not increased. Because W/S 97 is the largest size watershed under study it should, for smaller amounts of precipitation, produce the largest absolute changes in synthesized streamflows. Therefore, the recorded flows of W/S 97, the daily maximum and minimum temperatures, and the precipitation records were analyzed to determine the temperature below which all meltwater seemed to be refrozen.

This was done on a monthly basis using the five continuous years of data (1958-1963) available from Coshocton, Ohio. The results obtained are found below in Table 3. This criteria greatly increased the accuracy of the subroutine by improving the timing of the melt.

Some Input Parameters

MAXRAT is one of the most important input parameters in the snowmelt subroutine. It is this variable which determines the timing of the melt from the snowpack. If MAXRAT is initialized too high the cold content of the pack

Table 2. Temperature Cutoffs Between Rain and Snow

Month	Maximum Temp.	Minimum Temp.	Temperature Cutoff
November	34^{o}	6^{o}	$31^{o}F$
December	40^{o}	-6^{o}	$32^{o}F$
January	48^{o}	0^{o}	$35^{o}F$
February	54^{o}	0^{o}	$35^{o}F$
March	45^{o}	12^{o}	$32^{o}F$

Table 3. Temperature Cutoffs for Refrozen Meltwater

Month	Temperature Cutoff For Refrozen Meltwater
November	$22^{o}F$
December	$25^{o}F$
January	$29^{o}F$
February	$29^{o}F$
March	$31^{o}F$

will build up too fast and melt runoff will not occur. However, if MAXRAT is too low the cold content will not build up significantly and melt will be simulated before it had actually occurred. Hence, it is important to have MAXRAT high enough to allow some melting but low enough that all meltwater will not refreeze.

Trial and error was used to determine the optimum value of MAXRAT. When the timing of the snowmelt simulated the actual records it was assumed that MAXRAT was found to be .0001.

LIQW and QTI are the variables which may be used for the refinement of the quantity of snowmelt. Both are concerned with the fraction of incoming snow which is solid and liquid. By increasing the initial thermal quality of the snow and decreasing the liquid water content less melting will occur during the first few hours after the snow has fallen. An average value of .90 was assumed for QTI and .10 was assumed to be the initial value of LIQW.

CHANNEL SYSTEM EFFECTS

ROUTING

The routing technique used in the model is based on translating the stream inputs to an imaginary reservoir at the basin outlet then routing by level pool methods. The empirical routing method adapted for the watershed model assumed the time-area curve (average flow time from a subsection vs. area of the subsection) for a watershed would represent an outflow hydrograph from an instantaneous rainfall neglecting all attenuation due to storage; the time area curve was routed through level pool reservoir storage to form an outflow hydrograph. Figure 14 shows a time area histogram developed for a basin.

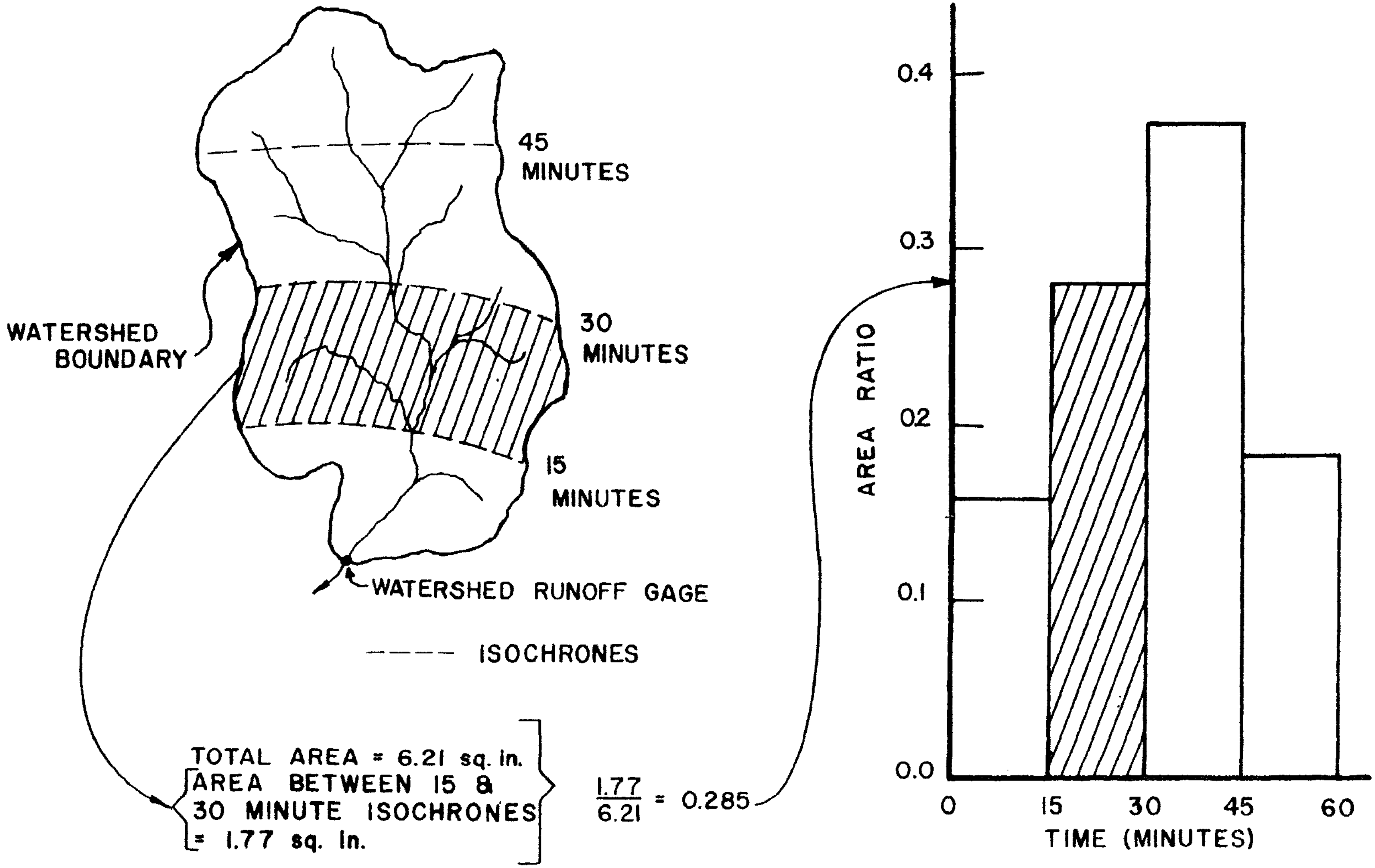


FIGURE 14. TIME - AREA HISTOGRAM DEVELOPMENT

Linsley et al. (1958) explain that the routing concept employed in the model need not be limited to uniquely deriving unit hydrographs. For a storm of duration equal to the interval between lines of equal flow time (isochrones) the average runoff may be estimated for each time zone and expressed (with proper conversion of units) in cubic feet per second. The resulting time-runoff diagram is then level pool routed to give an outflow hydrograph. If rainfall lasts for several time periods (a time period is the time of travel between isochrones, i.e., 15 minutes in Figure 14), the time-runoff diagrams are lagged, superimposed, and the summation is routed.

This procedure is justifiable since the entire system is a linear one and can be extended to readily include many channel inputs either within or without the basin.

The expressions used for routing in the O. S. U. version of the Stanford Model are essentially the same expressions as developed for the original model with the exception of the amount of reservoir type storage to use. In the Stanford Model the parameter KS1, which is dependent upon the amount of reservoir storage and the routing interval, was assigned a value and used for all routing conditions. In the O. S. U. version KS1 has been replaced by KSC and KSF, in an attempt to account for inbank or flood plain flows in accordance to techniques developed by James for the Kentucky Model. KSC is the routing parameter for low flows and KSF is the routing parameter for high flows. The program coordinates KSC and KSF with the current value of synthesized streamflow and CHCAP (the preassigned value for channel capacity). When the synthesized flow is less than one-half of CHCAP, KSC is used for routing; when the current synthesized flow is between one-half and twice CHCAP, the program interpolates between KSC and KSF; when the current synthesized flow is greater than twice CHCAP, KSF is used for routing.

INPUT AND OUTPUT OPTIONS

The original Stanford Model contained certain control options. Some of these have been modified or discontinued as well as new additions made in both the Kentucky and the Ohio State University versions. The control options as they exist in the O. S. U. version are presented below:

DKN (1) If 1, program prints out 15 minute values of rainfall, surface runoff, interflow, base flow, total flow entering the channel, and routed outflow all for one selected storm during the year. If 0, program does not print out these values. (See input format H.)

DKN (2)[a] If 1, program adjusts the input infiltration rate factor (C2) to make the synthesized results more in line with the recorded ones. (See subroutine "TEST".) If 0, program uses input factor without adjustment.

DKN (3) If 1, program reads in average daily evaporation over ten-day periods. If 0, program reads 365 or 366 daily evaporation values. (See input Format M.)

DKN (4)[a] If 1, program prints out daily flow error table (statistical evaluation of the simulation) at the end of the year. If 0, program neither calculates nor prints out daily flow errors.

---

[a] This option can be equal to 1 only if control option 9 is also equal to 1.

DKN (5) If 1, program prints out the 20 top hourly rainfall and the 20 top hourly runoff events during the year. If 0, program does not print out these values.

DKN (6) If 1, program prints out daily values of soil moisture storage (LZS). If 0, program does not print out these values.

DKN (7) If 1, program reads additional data and uses it to provide for snowfall and snowmelt. If 0, program treats all precipitation as rainfall. (Not operating, use zero always.)

DKN (8) If 1, program accepts input from more than one recording rain gage. If 0, program accepts input from only one recording gage. (Not operating, use zero always.)

DKN (9) If 1, program reads 365 or 366 daily recorded streamflows (average flow over the day in c.f.s.). If 0, program does not read these values and statistical evaluation can not be performed. (See input Format O.)

DKN (10) If 1, program will combine hydrographs for several basins in sequence. If 0, program treats the basin as one homogeneous unit. (Not operating, use zero always.)

DKN (11) If 1, program reads 365 or 366 daily values of flow diverted into or out of the basin. If 0, program does not read these values. (See input Format P.)

DKN (12) If 1, program routes streamflow on an hourly basis. (See input Format B.)

DKN (13) If 1, program makes streamflow routing a function of discharge. (See subroutine 'RTVARY".) If 0, program does not make the above change. (Not operating, always use zero.)

DKN (14) If 1, program prints out daily recorded streamflows. If 0, program does not print out these values. (See input Format O.)

DKN (15) If 1, program prints out all input data (echo check). If 0, program prints out only the values of the program control array (DKN (1) through DKN (15)).

DKN (16) If 1, program calls for the logarithmic plot. If 0, program does not call for the logarithmic plot. (If not operating, always use zero.)

DKN (17) If 1, program calls for the arithmetic plot. If 0, program does not call for the arithmetic plot.

DKN (18) If 1, program prints out daily values of SSEP, ISEP, EN, UZSN, UZS, GWS, SGW, SINT, SRGX, SSGWF, and LOS. If 0, the program does not print-out these values. (If not operating, always use zero.)

DKN (19) If 1, the program will print out hourly values of TEMP, RM, CDM, CVM, RADM, LIQW, PACK, and PX. If 0, the program does not print these variables. (If not operating, always use zero.

DKN (20) If 1, the program calls for an arithmetic plot of synthesized stream outflow along with the rainfall hyetograph for one select storm during each year of data. If 0, the program does not operate. If DKN (20) equals 1, then let DKN (16) and DKN (17) equal zero. Also call option 1

MODIFICATION OF THE STANFORD WATERSHED MODEL

Kentucky Version Of The Model

The Stanford watershed Model III was translated from ALGOL to FORTRAN IV by James (1966) and this translated and modified program became the Kentucky Version of the Stanford watershed model. Some of the modifications include simplified input data, a revised procedure for reading storage gage rainfall, making channel routing a function of streamflow, a revised UZSN dependent on evaporation and the ratio LZS/LZSN, and a print-out of the daily soil moisture storage. A more recent version of the Kentucky model has routines (OPSET) that automatically optimize some of the watershed parameters (James (1970)).

The Ohio State University Version Of The Model

The Ohio State University Version of the Stanford watershed model is based on the Kentucky version of 1967. It was first necessary to convert the program to the Ohio State University Computer System. Of the many changes necessary the most extensive was the relocation of the "day loop" from the main program to a subroutine. This modification made the program compatible with the storage space provided in the O. S. U. computer system for compilation. The program was first converted to the I. B. M. 7094 system and then to the recently installed I. B. M. 360 "time sharing" system (360/75, 370/165). The other changes in the model are discussed in the following sections.

SWAMP AND SOIL CRACK STORAGE

Runoff events from a test basin (the North Appalachian Experimental Watershed, Ohio) were poorly simulated during the fall months. Further investigations revealed that there are several swamps occurring along the course of the main stream, but by middle to late summer, they are dried up and the ground around them exhibits soil shrinkage cracks. This offered a very plausable explanation in that the extra runoff which the model simulated might well be going into soil crack storage and recharge of these swamps. The test watersheds will be described in detail later and their identity will be maintained in this discussion.

Simulation data for Watershed 94, using the March 5, 1969, Ohio State University version of the model, was examined to see if a relationship did, indeed, exist. The data which had been loaded on punched cards was for the five year period water years 1958 through 1962. Of these years, no large precipitation events occurred during water years 1958 and 1960 until after mid-January. The other three years, however, all had easily measurable amounts of precipitation during the fall months. For the years 1959, 1961, and 1962, the area between the recorded and simulated discharge curves was planimetered and the volume was found to be about 250 acre feet in all three cases.

While this was too large a volume to be accounted for by the six swamp and marsh areas of Watershed 94, these areas, together with soil crack storage, might account for this volume. The planimetered volume was converted to inches of water over the watershed and added to upper zone storage (depression storage and storage in highly permeable surface soils). It was determined by a process of trial and analysis that the most suitable period of application for this increase in upper zone storage was July 1 to November 30. This seems consistent with field observation which indicates that the soil begins to dry out in July and August and its moisture level generally continues to drop until restored by winter season precipitation. This increase in upper zone storage greatly improved simulation. However, even though the value of upper zone storage was unmodified for the period December 1 to June 30, carry-over effects from other calculations where upper zone storage was involved greatly altered simulation results for the remainder of the year. This necessitated application of a negative upper zone storage to the period December 1 to June 30. The procedure for introducing these quantities into the model is discussed below.

The parameter which accounts for swamp and soil crack storage is called FACTOR. Two pieces of input data, AREA (basin area in square miles) and VOLUME (volume of water in acre feet allocated to swamp and soil crack storage) are required to calculate it. FACTOR is introduced in subroutine DYLOOP and is computed as.

FACTOR = (VOLUME * 12.0) / (AREA * 640.0)

Its units are inches of water over the entire basin. FACTOR is added to or subtracted from nominal upper zone storage (UZSN) as the season requires.

MULTIPLE RECESSION CONSTANTS

The model treats the recession portion of the runoff hydrograph as a depletion curve, which may be represented by the characteristic decay equation:

$$q_1 = q_o K_r$$

Where q_o is the flow at any time, q_1 is the flow one time unit later, and K_r is a recession constant less than unity. In areas of relatively uniform soil conditions, for which the model was developed, only a single groundwater recession constant is necessary.

Areas of stratified geology, particularly where continuous clay layers exist, present a marked contrast. The clay layers have considerably lower permeabilities and thereby control the rate of groundwater percolation. Depending on the thickness and vertical distribution of the clay layers, a number of groundwater recession constants may be required to correctly develop the depletion curve.

Figure 15, the column profile, shows the various soil and rock strata encountered in Watershed 97, the major watershed of the North Appalachian Experimental Watershed. There are nine well defined clay layers, ranging from three to over five feet in thickness. These layers, being less pervious, create definite break points in the recession limb of the hydrograph, as may be seen in the semi-log hydrograph plot of Figure 16. This necessitated the introduction of the concept of multiple recession constants into the model.

The general procedure used for fitting the recession curve by computer is the Barnes' method. The runoff hydrograph is first plotted from the input data as a semi-logarithmic curve with flow on the logarithmic scale and time on the arithmetic scale.

As the runoff hydrograph is being plotted, a running tally is made of the largest discharge value. After the entire graph is plotted, and starting at the hydrograph peak, the slope between successive data points is computed and the

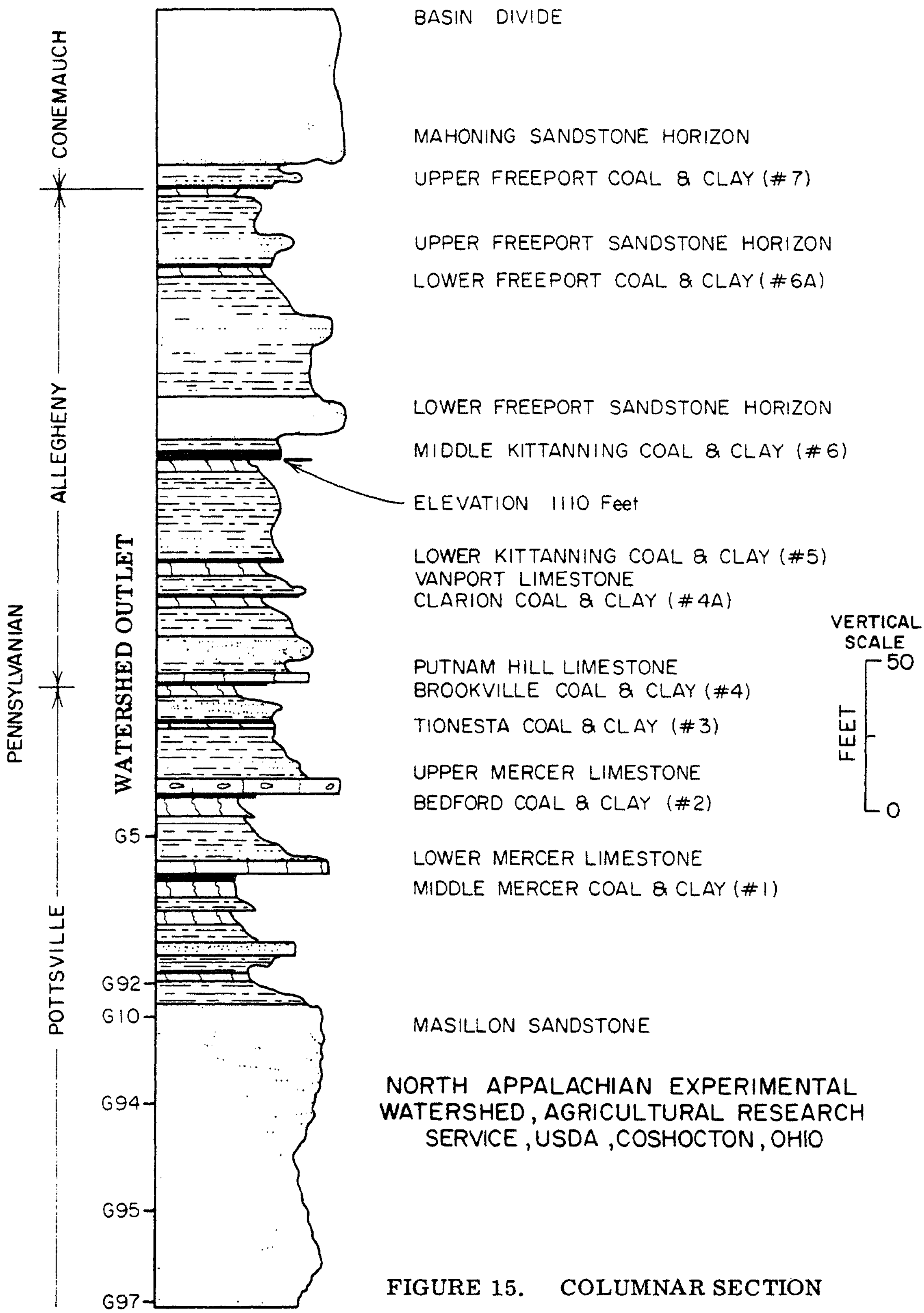


FIGURE 15. COLUMNAR SECTION

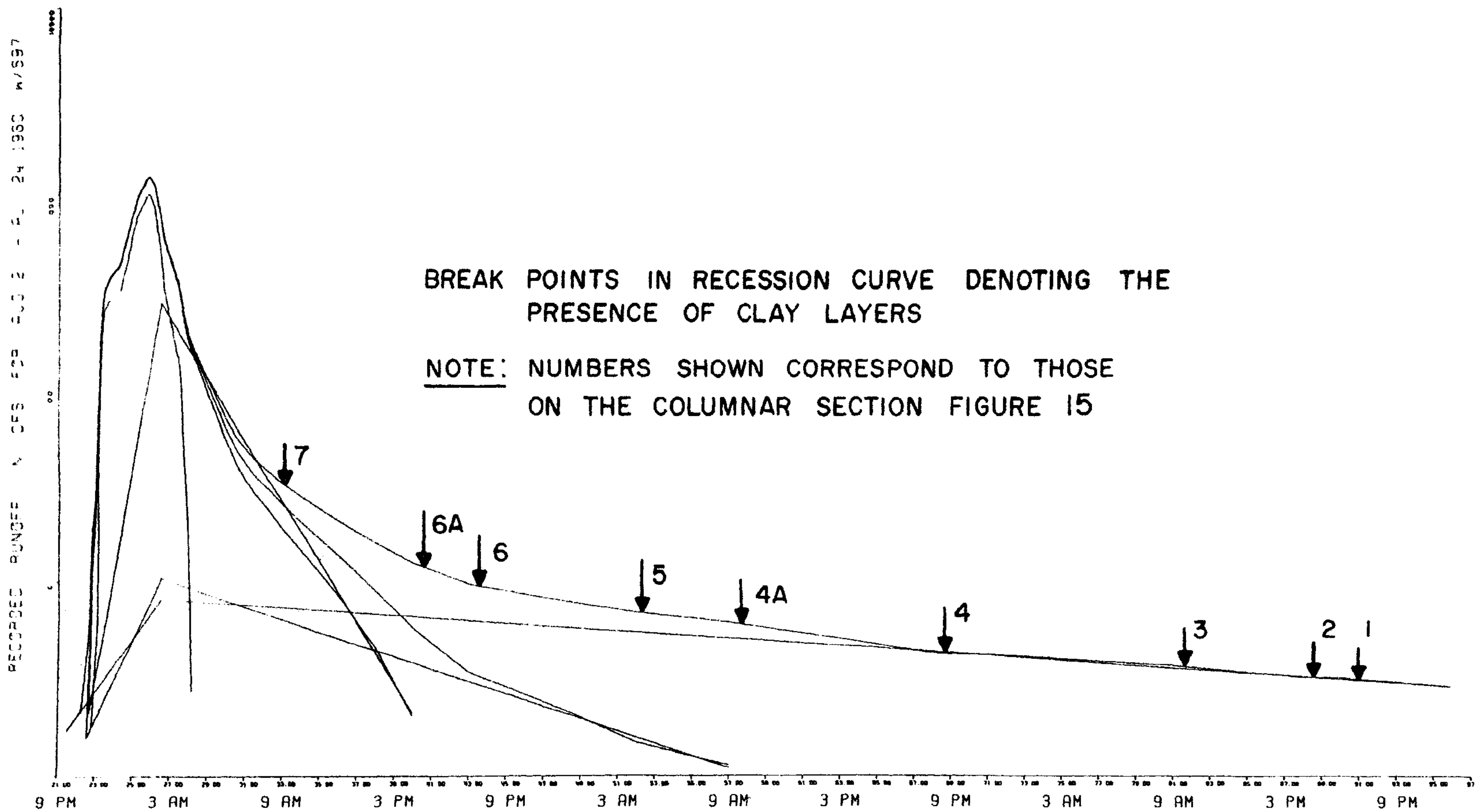


FIGURE 16. SEMI - LOG HYDROGRAPH SHOWING BREAK POINTS

point of maximum slope is taken as the inflection point of the recession limb.

A subroutine is then called to fit a straight line, by the method of least squares, to the recession limb of the hydrograph. The subroutine starts with the last data point and works backward, toward the inflection point, adding one point at a time.

While only two points are required to determine a unique straight line a minimum of three data points are used in the program's least squares subroutine. It was decided that the addition of a third point would give an extra degree of freedom and thereby help to dampen the effects of random error of observation which might occur in recording the runoff.

After the first straight line is fit using three data points, a second line is fit using the first four data points. The difference in slopes is calculated as an absolute error and compared to a predetermined value.

If the slope is less than the test value, a straight line using the first five data points is determined. Its slope is then compared to the slope of the line determined by four data points. If this slope is less than the test value, a sixth data point is added and the slope of this line compared to the slope of the line using five data points. The process continues adding one data point at a time. As soon as the absolute error is greater than the test value the subroutine returns to the main program the slope and intercept of the next to last straight line which was computed. These values are then used to compute a straight line from the inflection point on the recession limb to the end of the discharge hydrograph.

A straight line is then fit to the first point of the discharge hydrograph and the point under the recession limb inflection point as determined by the other straight line.

The differences in ordinate values between the discharge hydrograph and the computed straight lines are then plotted to form a new hydrograph.

Each time a straight line is fit to the recession limb, it has an associated daily recession constant which is determined as follows:

$$K_r = \left[\left[\frac{Q_s}{Q_i} \right]^{\frac{1}{T_s - T_i}} \right]^{24}$$

Where K_r is the daily recession constant, Q_s is the computed discharge in cfs of the first point fit to the straight line, Q_i is the computed discharge in cfs at the inflection point, and T_s and T_i are the respective times in hours. As long as the computed value of K_r is greater than some minimum value, the program returns to the least squares subroutine and fits a new straight line. By a systematic analysis, using several storms and various size (122 to 4580 acres) watersheds, it was determined that a difference in slopes of 0.0001 would be the criteria for the model. This value was the largest which permitted reproduction of results from storm to storm.

The mechanism for dealing with multiple recession constants is a self-contained card set which may be inserted into the program as required. It was decided to handle the problem in this manner so that users who need only one groundwater recession constant would not be inconvenienced or confused by having to read in zero data sets. Also, the adopted scheme allows for the easy addition of as many groundwater recession constants as are required by a given problem. The program card set SM00015 - SM00018, operates as follows:

1. The smallest daily groundwater recession constant (i. e., the one corresponding to the highest range of discharge values) KK24 is read as input data.
2. When DR, the average daily synthesized streamflow becomes less than the cut-off value, a new recession constant is introduced by the following statement:

   IF (DR (I-1) . LE . 20. 0) LKK4 = 1 . - (. 732135) ** (1. 0/96. 0)

Where 20. 0 is the cut-off value from Table 4, 0. 732135 is the daily value of the input recession constant from the same table, and LKK4 is the logarithm of the hourly baseflow recession constant. The above test may be used as many times as needed simply by changing the test value and the hourly recession constant to the appropriate numbers.

TIME INCREMENT CHANGES

Since the model was originally designed for large watersheds and entire river basins, the streamflow routing procedure is based on a fifteen-minute flow increment. Consequently, the model will fail to properly respond to precipitation inputs on small watersheds with a time of concentration less than fifteen minutes, and on watersheds with only a few time-area histogram elements particularly those with large relief. To apply the model to small agricultural and other watersheds it became necessary to modify the model's fixed fifteen-minute computational scheme to an optional smaller interval, down to one minute interval.

STORM OF APRIL 25 - 27, 1961					
WATERSHED	DAILY INTERFLOW RECESSION CONSTANT (HOURLY)	DAILY GROUNDWATER RECESSION CONSTANT (HOURLY)	RANGE OF APPLICATION	DAILY GROUNDWATER RECESSION CONSTANT (HOURLY)	RANGE OF APPLICATION
5	0.01061444 (0.82745752)	0.70906091 (0.98577654			
10	0.04404320 (0.87800088)	0.64678574 (0.98200798)			
92	0.00000055 (0.54850650)	0.72377318 (0.98662042)	0.0 1.0 cfs	0.11309069 (0.91318643)	1.1 - 2.0 cfs
94	0.00472898 (0.80004665)	0.73213464 (0.98709273)	0.0 20.0 cfs	0.12571520 (0.91722205)	20.1 - 35.0 cfs
95	0.00000007 (0.50336044)	0.67811352 (0.98394524)	0.0 5.0 cfs	0.02156273 (0.85225780)	5.1 - 12.0 cfs
97	0.00007879 (0.67455851)	0.59544742 (0.97862988)	0.0 80.0 cfs	0.02433473 (0.85656325)	80.0 - 100.0 cfs

Table 4. Multiple Recession Constants

Following a thorough study of the model's components and flow charts, all statements involving the previously fixed fifteen-minute calcualtion were changed to accommodate a variable updating time increment. The parameter FRAC, the selected routing interval (TINC) expressed as a fraction of an hour, was introduced to accomplish this requirement. FRAC was inserted in every computation involving a value updated at the end of the routing time increment. An example of this change is the following:

BEFORE: EPX = 0.25 *EPXM
(0.25 - fixed 15 minute fraction of hour)

AFTER: EPX = FRAC *EPXM
(FRAC - selected routing interval fraction of hour)

The parameters affected along with corresponding statement numbers are as follows·

EPX	(LV0046)	ROFF	(LV0114)
PR	(LV0108)	SFX	(LV0116)
D4F	(LV0109)	BASFLW	(LV0118)
ROS	(LV0110)	OUTFLW	(LV0119)
UROS	(LV0112)		

However, there are two limitations in selecting the routing time increment (TINC) which should be noted:

1. TINC must be evenly divisible into the time of concentration (TCONC) to obtain an even number of time-area histogram elements (Z).
2. TINC must be evenly divisible into 60 minutes to insure an even multiple of intervals (NINC) in the hour loop. Based on this criterion, the

possible choices of TINC are 1, 2, 3, 4, 5, 6, 10, 12, 15, 30, and 60 minutes.

EXAMPLE: A watershed with a time of concentration of 15 minutes has the following possible combinations·

TINC	Z	NINC
15	1	4
5	3	12
3	5	20
1	15	60

Major changes can also be found in the hour loop

BEFORE: DO 14 DD23 = 1, 4

AFTER: DO 14 DD23 = 1, NINC (LV0107)

and in the interflow recession constant

BEFORE: IRC4 = IRC ** (1./96.)

AFTER: IRC4 = IRC ** (1./ (24.*60./FLOAT (TINC))

where IRC is the daily interflow recession constant, IRC4 is the TINC-minute interflow recession constant, and the exponent is the reciprocal of the number of TINC - minute increments per day.

SNOWMELT SUBROUTINE

As previously explained in the earlier section "Snowmelt," an entirely new snowmelt subroutine was created for regions, like Ohio, with small amounts of snow and without extensive snow survey data. All the details about the snowmelt subroutine can be found in that section.

INPUT MODIFICATIONS

The original model contained 15 control options, DKN (JJJ). The path followed by the option is controlled either by one or zero. Five additional DKN control options, DKN (16) through DKN (20) were introduced (see Input and Output Options).

The original option, DKN (1), could only print out the details of one select storm for the entire period of data. So as to investigate several storm hydrographs, IOUT, IIOUT, and INUM were made variables; this permitted the selection of one storm for each year of record. The variables were written as IOUT (MM), IIOUT (MM), and INUM (MM); the counter MM was introduced to yearly update the variables.

If N years of data are to be synthesized, then N different storm data values should be read in. This was accomplished by introducing the variable YRDET which is the number of years being analyzed. The input should be in the following card sequence if DKN (1) equals 1:

1. One value of YRDET on one card in an I5 Format.
2. For each year of record, detail storm data consisting of

    a. One value of IOUT (I) and INUM (I) on one card in a 2I5 Format;

    and if DKN (20) simultaneously equals 1, this additional input is required

    b. Detail Storm Axes Data

        One value of XORG, XAX, XTIC, XUNIT, YORG, YAX, YTIC, YUNIT, ZTIC, and ZUNIT on one card in a 10F5.2 Format.

c. X-Axis Label (DDX)

Up to 32 characters on one card in a 8 (1x, A4) Format.

d. Y-Axis Label (DDY)

Up to 88 characters on two cards in a (20A4/2A4) Format.

e. Streamflow Data

One value of TIME and ROFF on one card in a 2F10.2 Format. A sentinel card must be used to indicate that all runoff data for the storm has been read. The sentinel card follows the above format with ROFF = 0.00.

f. Precipitation Data

One value of HOUR (I) and RAIN (I) in a 2F10.2 Format. The sentinel card follows the above format with RAIN (I) = 100.0.

The time-area histogram input, which follows the program control array data, was changed to accomodate the variable routing time increment. The following is the proper revised card sequence:

1. One value of TCONG, TINC, and Z on one card in a 3I5 Format.
2. One time-area histogram ordinate value (C) on each of Z cards in a F10.3 Format.

Other input modifications are as follows:

QQY, a alphanumeric data for labeling the ordinate of the runoff hydrograph, has been added to the data set following QQO, the description of the gage location. The data consists of the units of flow, the water-year, the watershed number, and the raingage number. A different QQY is needed for each water year of data.

READ: Up to fifty-six characters from one card with a 14A4 Format.

SYM, alphanumeric data for labeling the abscissa of the runoff hydrograph, which is invariant during execution of the program for every water-year, has been incorporated as part of the program with the following DATA declaration statement:

```
DATA SYM/3HOCT, 3HNOV, 3HDEC, 3HJAN, 3HFEB, 3HMAR, 3HAPR
     3HMAY, 3HJUN, 3HJUL, 3HAUG, 3HSEP/
```

OUTPUT MODIFICATIONS

PLOT SUBROUTINES

To facilitate the analysis of results subroutines were added to plot recorded and synthesized runoff hydrographs. Also for selected storms, its rainfall hyetograph plot is superimposed over the responding hydrograph. Following are the added plot subroutines:

LOGPLT - Plots the recorded flows on a five-cycle log scale that ranges from 0.01 to 1000.0 cubic feet per second.

LOGPL - Plots the synthesized flow in cubic feet per second with a dashed curve on the same log scale used in LOGPLT.

ARITHP - Plots the recorded flows in cubic feet per second on an arithmetic scale of the user's choice.

ARITH - Plots the synthesized flows in cubic feet per second with a dashed curve on the same arithmetic scale used in ARITHP.

DASHC - Used in subroutines LOGPL and ARITH to plot the dashed hydrographs.

Subroutines LOGPLT and LOGPL have the important significance of highly emphasing the low flows which can be of great help in matching the hydrograph recessions and studying low flow periods.

With the present computer program structure, first the daily average recorded streamflows in cubic feet per second, for the user's choice of scale, will be plotted versus time in days. Next, on this same set of axes, the synthesized streamflows computed by the model will be plotted with a dashed curve. With this superposition of recorded and synthesized results, the user can immediately detect when the model is not synthesizing correctly. The option to plot logarithmically or arithmetically is regulated by DKN (16) and DKN (17), respectively.

If one of the above mentioned options is called, the computer will punch out cards to plot the runoff hydrograph for every water-year that is synthesized. Then, to obtain the plot, these cards are fed by the user to an I. B. M. 1130 or I. B. M. 1620 computer that drives the I. B. M. 1627 plotter. If the user desires a plot, it is suggested that either an arithmetic or logarithmic plot, but not both, be called to prevent mixing of cards for the two different plots. Following is a listing of the plotting subroutines implemented in the supplementary program and output control options DKN (16), DKN (17), and DKN (20).

Examples of these plot outputs are shown in the Figures of the simulation results.

Subroutine - AXIS

The purpose of subroutine AXIS is to draw an axis with tic marks, annotate the tic marks with numeric values, and write a desired title.

The following is an explanation of the arguments of the subroutine:

General FORTRAN Statement:

CALL AXIS (X, Y, BCD, NC, SIZE, THETA, YMIN, DELY, DIST)

X, Y — are the floating point coordinates of the axis origin.

BCD — is the title information (literal characters). This had been left blank in the O. S. U. Version with subroutine SYMBOL used for labeling the axes.

NC — is the number of characters in the title including blands. If NC is negative, tic marks, title, and annotation characters are printed on the clockwise side of the axis.

SIZE — is the axis length in floating point,inches.

THETA — is the angular orientation,in floating point degrees,of the axis from the commonly assumed X-axis direction. THETA equals 0. for the X-axis. THETA equals 90. for the Y-axis.

YMIN — is the floating point numeric label for the minimum value of Y used at the axis origin (X, Y).

DELY — is the floating point increment for a corresponding one inch along the axis.

DIST — is the spacing between tic marks in floating point,inches.

<u>Subroutine - SYMBOL</u>

The purpose of the subroutine is to draw the alpha-numeric characters labeling the axes of the plot. The following is an explanation of the arguments of the subroutine·

General FORTRAN Statement:

CALL SYMBOL (X, Y, HGHT, BCD, THETA, N)

X, Y	are the floating point coordinates of the lower, left corner of the first character to be drawn.
HGHT	is the height of the characters in floating point,inches.
BCD	is the location of the first character of alphanumeric information to be drawn.
THETA	is the counter-clockwise angular rotation from the X-axis, in floating point degrees,along which the alphanumeric title is to be written. THETA equals 0. for the X-axis and 90. for the Y-axis.

```
CALL SYMBOL  (DX, -.8  .28, DDX (I), 0., 4)
CALL SYMBOL  (-1.0, DY, .28, DDY (I) 90., 4)
```

Subroutine - PLOTBD

The purpose of PLOTBD is to set bounds (relative to the origin) within which the pen is to plot. If the user tries to plot a point out of bounds, the pen will plot to the boundary, go to where the line comes back in bounds and continue. The following describes the arguments of the subroutine:

General FORTRAN Statement:

CALL PLOTBD (XLE, XRI, YLO, YHI, I)

XLE	is the left boundary in floating point.inches.
XRI	is the right boundary in floating point inches.
YLO	is the lower boundary in floating point.inches.

YHI is the upper boundary in floating point,inches.

I determines the action when a boundary is crossed.

If I equals 0, no indication is given that the boundary has been crossed.

If I equals 1, an arrow will be drawn where the pen was going out or coming in bounds.

The FORTRAN statement used in the program for setting the plot bounds is the following

CALL PLOTBD (15., XAX + 10., -5., YAX + 1., 1)

Subroutine - PLOT

The purpose of subroutine PLOT is to move the plotter pen from its present position to one specified by the arguments of the subroutine, an explanation of which follows:

General FORTRAN Statement:

CALL PLOT (X, Y, IC)

X, Y are the floating point coordinates to which the pen is to move.

IC is the pen and origin definition control.

If IC is even, then pen down while moving.

If IC is odd, then pen up while moving.

If IC is negative, a new origin (0, 0) is defined at (X, Y).

Subroutine - PLOTE2

The purpose of subroutine PLOTE2 is to assure that all the output cards for the specific plot are obtained. This subroutine should be placed at the termination of the above mentioned plotting packages.

OPTION TO PRINT-OUT DAILY WATERSHED INTERACTIONS

In an attempt to obtain a better indication of the model's interactions in the upper, lower, and deep lower zones, statements were added to the program at the end of the hour-loop in subroutine DYLOOP to allow a print-out of end-of-day values of the following:

SEEP - An evaporation parameter used to vary infiltration.
(Up-dated daily at 4 P. M.)

ISEP - An evaporation parameter used to vary infiltration.
(Constant for an entire water-year)

EN - Factor varying infiltration by season.
(Up-dated daily at 4 P. M.)

UZSN - Soil surface moisture storage index.
(Up-dated every 15 minutes)

UZS - Current soil surface moisture storage.
(Up-dated every 15 minutes)

GWS - Current value of groundwater slope index.
(Up-dated every 15 minutes)

SGW - Groundwater moisture storage.
(Up-dated every 15 minutes)

SINT - Variable used to sum synthesized daily interflows.
(Starts at 0.0 at the beginning of each new month and is up-dated every hour)

LOS - Groundwater evaporation.

(Up-dated every hour)

The option to print these values is governed by DKN (18).

GENERAL MODIFICATIONS

In addition to the specific changes mentioned above several minor changes have been made. For example, to allow the program to change yearly the value of ISEP, an evaporation parameter which varies infiltration, the following statements were added to the main program after card number 309:

```
AET = 0.0
DO 8024 I = 1, DPY
8024 AET = AET + E (I)
IF (EVCR (6) . NE . 1.0) AET = 0.7 * AET
ISEP = 24.0 * AET/365.0
```

The variables used above are defined in the listing of program variables.

As another example, if the plotting options, DKN (16) or DKN (17), are not exercised, the program reads extraneous hydrograph axes data. To omit having to add this data, insert statement (LV0009)

```
IF (DKN (16) .AND.DKN (17).EQ.0) GO TO 4500.
```

Some parameters have been incorporated as part of the input parameter data and several format statements have been changed. Most of the changes and modifications are indicated in the program listing; the card identification numbers are preceeded by letters, for example, LV009, DB0047, WM0316, SMO0018, etc.

APPLICATION TO SMALL AGRICULTURAL WATERSHEDS

General Description Of The Study Area

The data used to test the model were obtained from the North Appalachian Experimental Watershed (NAEW) located near Coshocton, Ohio. NAEW was started in 1935 and is being operated by the Soil and Water Conservation Branch of the Agricultural Research Service of the U. S. Department of Agriculture.

LOCATION

The North Appalachian Experimental Watersheds are located about ten miles north of Coshocton, Ohio, in the Muskingum River Basin. The experimental area lies south of the limits of glaciation, at a latitude of 40^{o} 22' North, and within an elevation range of 800 to 1,300 feet mean sea level. This site typifies much of the agricultural land in the unglaciated Allegheny Plateau which covers part of southeastern Ohio, western Pennsylvania, western West Virginia, a portion of eastern Kentucky, and central Tennessee. Figure 17 shows the location of Coshocton in Ohio and the Little Mill Creek Watershed study area.

CLIMATE

The precipitation pattern at the study area conforms to the Ohio River Valley Pattern. Summertime rainfall is featured by the convective-type storm usually of high intensity but short duration and covers a small area. Winter precipitation is mainly due to cyclonic-type storms generally of low intensity but long duration and covering a large area. Snowfall is not a major source of precipitation at the

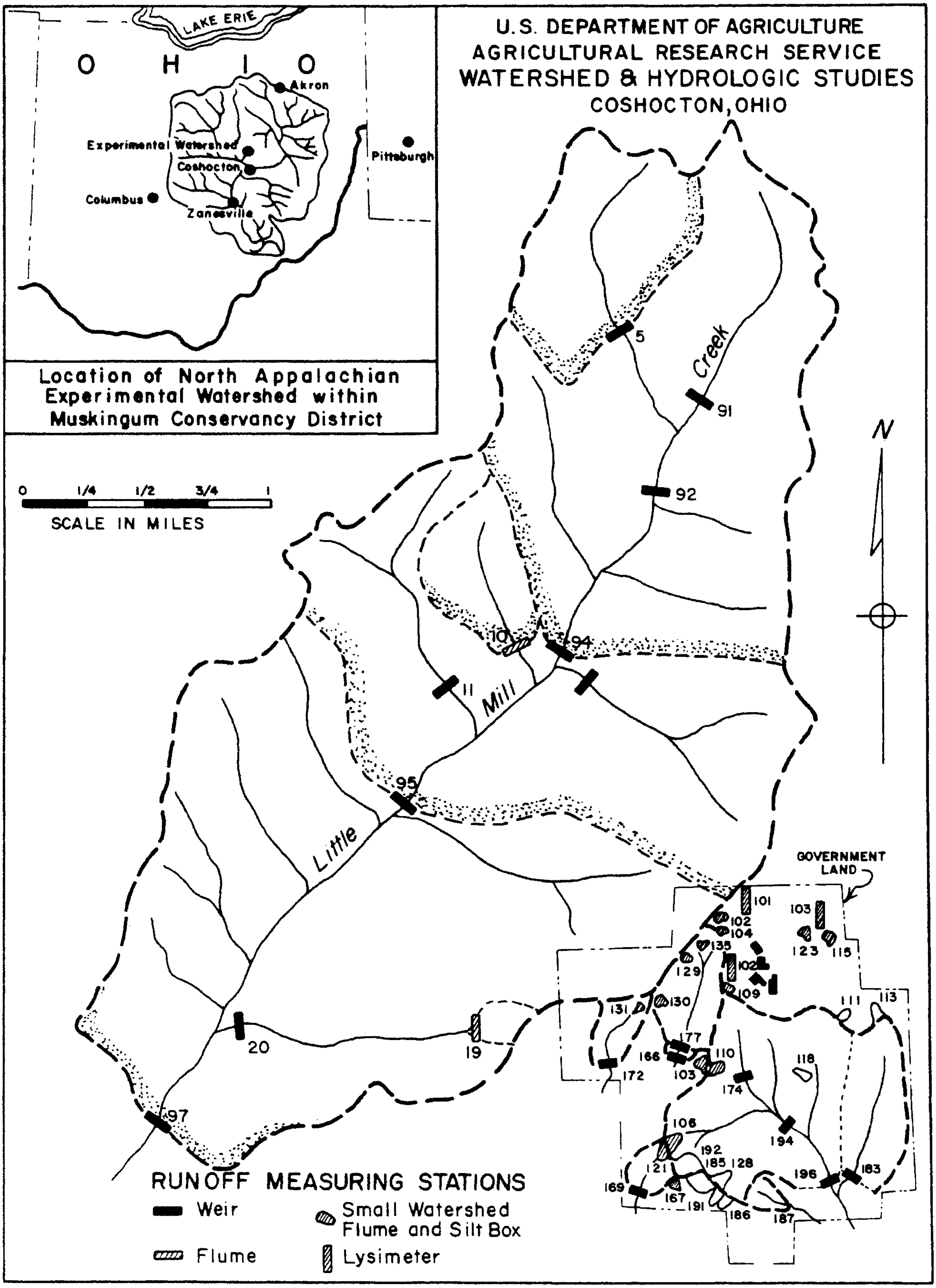


FIGURE 17. NORTH APPALACHIAN EXPERIMENTAL WATERSHED

station. The average snowfall amounts to 24 inches per year which is about 5 percent of the total precipitation. Based on a 31-year record (1937-68), the average annual precipitation at the station is 37.16 inches and ranges from a recorded minimum of 27.61 to a maximum of 48.92 inches.

During the 25-year period (1937-62), the average mean monthly temperature is 50.3 degrees Fahrenheit. The highest monthly average of maximum temperatures and the lowest monthly average of minimum temperatures are 92.4 and 0.4 degrees Fahrenheit, respectively. The ground is frozen on the average of 57 days per year and frost reaches a depth of about 13 inches.

The growing season amounts to an average of 178 days per year and extends from April 28 through October 23. The distribution of precipitation and temperature during the year is almost ideal for the growth of corn and grasses.

GEOLOGY

The bedrock strata of the area consists of the sandstones, shales, clays, limestones, and coal and iron ores of the upper Pottsville, the Allegheny and the lower Conemaugh series of the Pennsylvania system. The strata were eventually elevated above sea level. As a result, the process of weathering developed and valleys and hills were formed. Later crustal movements lead to uplifting of this erosion surface at the time the Allegheny Plateau was formed.

Ice advance during the Pleistocene time stopped a few miles north and west of the study area. This introduced a new factor in the modification of the land surface by filling old valleys and diverting streams so that new valleys and new drainage systems were formed in regions untouched by glacial ice. Harrold, et al.

(1962) reported that little change was made in the drainage system of the experimental watersheds and the area immediately south.

The most significant feature of the geologic structure in the study area is the Cambridge Arch. The crest of the arch runs generally north to south. The Cambridge Arch is prominent through most of east-central Ohio; it is not entirely a local occurrence. A typical columnar section of the strata underlying the Coshocton watersheds is shown in Figure 15.

SOILS

The most extensive soil[1] series on the experimental watersheds is the Muskingum, an upland soil developed from sandstone and shale. The surface soil of the Muskingum silt loam is brown to yellowish brown, generally about six to eight inches thick. The subsoil is yellowish brown, contains occasional sandstone and shale fragments, ranges from five to eight feet deep. Surface and internal drainage are good. The chemical characteristic is normally acid. Muskingum loam is derived largely from sandstone and is coarser in texture throughout the profile than Muskingum silt loam. It is rather shallow and contains numerous sandstone fragments.

PHYSICAL AND HYDROLOGIC CHARACTERISTICS

Table 5 gives data on the physical and hydrological characteristics of the experimental watersheds.

---

1. Current updating may find new names for these soils on the maps.

Table 5. Watershed Characteristics

Watershed	Drainage area acres	Length of principal water-course feet	Average slope percent	Aspect	Peak discharge of record cfs	year	Land Use
5	349	4,900	15.5	SE	382	1957	Mixed cover under conser-vation practice
10	122	3,400	16.2	SE	216	1957	do
92	920	9,500	15.4	S	578	1957	do
94	1,520	13,700	15.9	SW	1404	1957	do
95	2,570	18,700	16.9	SW	1590	1957	do
97	4,580	29,500	17.2	SW	3345	1957	do

Determination Of Input Parameters

The input parameters have been approximately divided into four groups and the determination of their values are discussed below.

MEASURABLE INPUT PARAMETERS

Parameters in this group are loosely called measurable if they can be measured in the field or from maps, if they can be computed from formulae, or if they can be systematically estimated.

Nineteen parameters are discussed in this group:

A - is the impervious area that drains directly into the stream channel; impervious areas from which the runoff must cross a pervious area before reaching the channel. A may be measured directly from aerial photographs. It is usually zero for rural or undeveloped areas unless there are large areas of exposed rock.

AREA - is the watershed drainage area in square miles. Topographic maps and aerial photographs are the most common means to establish watershed boundaries.

CHCAP - is the index capacity of the existing channel in cubic feet per second. This factor is estimated by determining the gage height at bankfull flow and reading the capacity directly from the rating curve.

COE - is the empirical constant for convection.

COE $= 0.00184 \times 10^{-0.0000156h}$

where the portion $10^{-0.0000156h}$ represents the change of the barometric pressure due to the change in elevation h above sea level.

ETL - is an estimate of the stream and lake surface area as a fraction of the total watershed area. It is estimated from topographic maps or aerial photographs.

EVCR - is the monthly evaporation pan coefficient. It may be determined by taking a ratio of the computed daily values of lake evaporation (averaged over the month) to the computed daily values of pan evaporation (averaged over the month).

IRC - is the daily interflow recession constant. It may be estimated by graphical techniques for hydrograph analysis developed by Barnes (1940).

K1 - is the long term ratio of average rainfall over the basin to the average rainfall over the study watershed. It acts as an adjustment factor if the precipitation of the watershed being simulated is different from the pattern at the recording gage. K1 may be determined by any precipitation weighting technique such as arithmetic averaging, Thiessen method, or isohyetal method.

KK24 - is a daily baseflow recession constant which controls the rate of discharge from the groundwater table. It can be estimated by graphical techniques discussed by Barnes (1940). Multiple recession constants have been discussed in the previous chapter.

KSC - is the streamflow routing parameter for low flows. It is used to account for channel storage when channel flows are less than one-half of the channel capacity.

$$KSC \text{ or } KSF = \frac{K - 0.5t}{K + 0.5t}$$

where t is the routing period;

$$K = - Q/\frac{dQ}{dt}$$

where $\frac{dQ}{dt}$ is the slope of a line tangent to the hydrograph at the point of contraflexure, and Q is the surface runoff flow rate at the point of contraflexure. A hydrograph with inbank flows should be used.

KSF - is a stream routing parameter for flood flows. It is used to account for channel plus flood-plain storage when stream flows are greater than twice the channel capacity. KSF can be calculated using the above formula, however, a hydrograph of flood flows should be used.

L - is the mean overland flow path length in feet. It can be estimated from topographic maps or aerial photographs. For this model, the periphery of the watershed boundary, on a topographic map with a contour interval of 5 feet and a scale of 1 inch equals 400 feet, was divided into 200 feet increments. Then at each increment point the distance perpendicular across the contours to the nearest channel was measured; this average was used for L.

SS - is the average ground slope in feet per foot of the overland flow surfaces perpendicular to the channel. To measure SS, a topographic map of the watershed is overlain with a grid system. The slope is determined at each grid intersection by measuring the distance between two contour lines and dividing the contour interval by this distance. The values are then averaged for the entire watershed to establish a value of SS.

TAREA - is the total watershed drainage area in square miles. Photographic maps and aerial photographs could be used to establish its value.

VOLUME - is the volume of water assigned to swamp storage and dry ground recharge in acre feet. If there are no swamps, VOLUME equals 0.0. If swamps dry up and the model is over simulating in the fall, the value of VOLUME may be estimated by planimetering the area between the recorded and simulated discharge curves, in second foot days, and converting it to acre feet.

WSG -is a storage gage weighting factor. It is defined so that the average rainfall over the basin is the product of WSG and the storage gage rainfall plus the product of (1-WSG) and the recording gage rainfall.

TCONC -is the time of concentration, i.e., the time (in minutes) for water originating in the most remote region of the watershed to reach the measuring station. One of the empirical formulae for determining the time of concentration is

$$TCONC = 0.0078 \left[L/S^{1/2} \right]^{0.77}$$

where L is the horizontal length in feet from the most distant point in the basin to the outlet, and S is the slope between these points.

C - is the time-area histogram ordinate value.

Z - is the number of elements in the current time-area histogram.

C and Z are determined as follows:

1. Applying a suitable time of concentration formula, like TCONC shown above, and using a suitable topographic map, compute the flow time from various locations along the main channel and tributaries of the basin and note these times on the topographic map as shown in Figure 18a.

2. By interpolating between the noted times, draw lines of equal flow times (isochrones) as in Figure 18b where 15 minute isochrones are drawn.

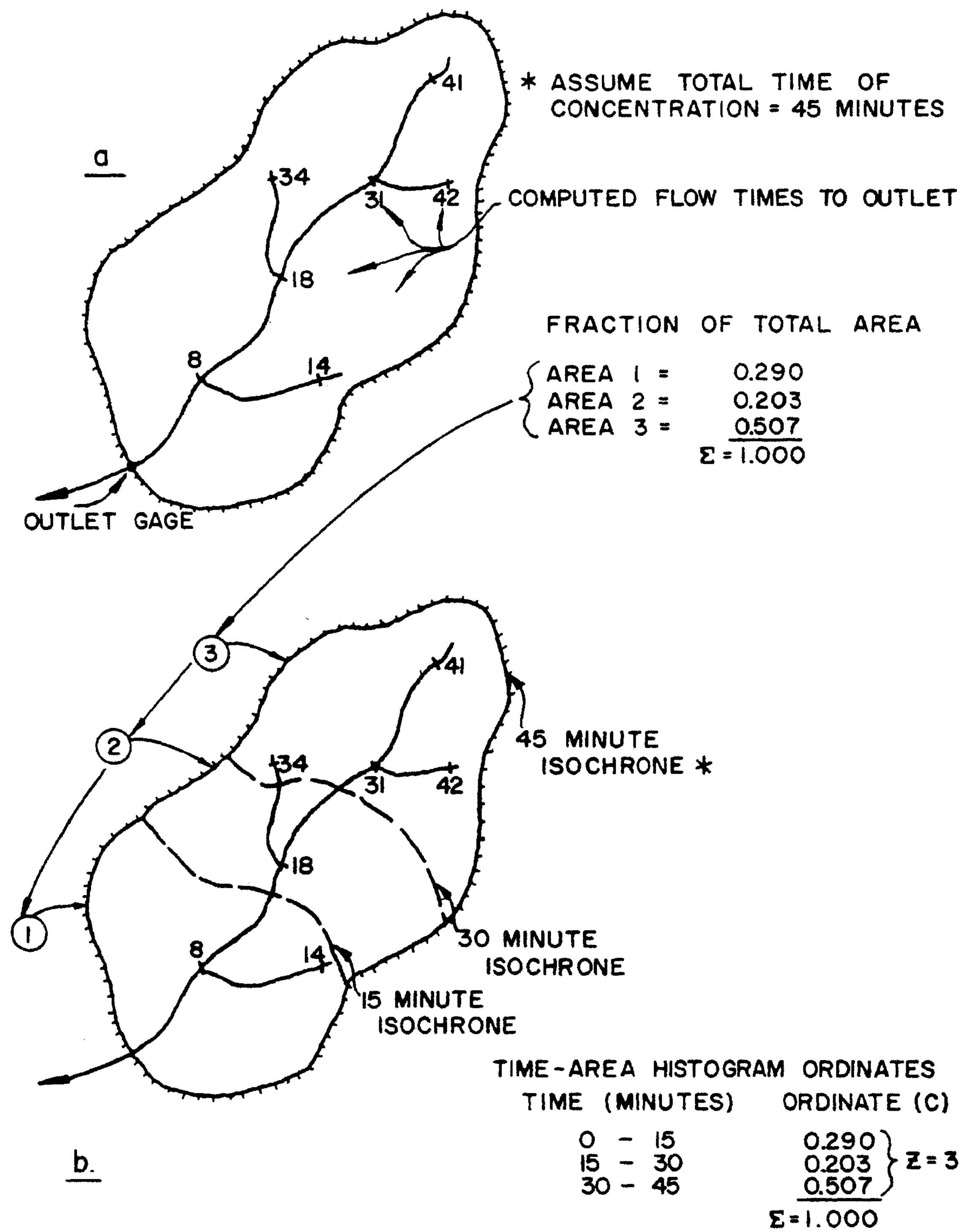


FIGURE 18. DEVELOPMENT OF TIME - AREA HISTOGRAM

3. From measurements of the area bounded by each pair of isochrones, compute the fraction of the total watershed within each pair. Figure 18b shows sample computations and the corresponding values of C and Z.

INPUT PARAMETERS DETERMINED BY TRIAL AND ADJUSTMENT

This group of parameters are determined by trial and adjustment depending on the values returned by the model. Some of the parameters have guidelines for determining their initial values; the initial values for the others are determined by experience or by examining suggested value ranges. Twelve parameters are discussed in this group.

CB - is an index that controls the rate of infiltration. It is primarily governed by soil permeability and the volume of moisture that may by stored within the soil. An initial value of 0.85 was used for the Little Mill Creek Watershed.

CX - is an index for estimating the capacity of the soil surface to store water in interception and depression storage. A value 0.7 was initially chosen for Little Mill Creek.

CY - is an index controlling the time distribution and quantities of moisture entering interflow. An initial value of 3.0 was selected for Little Mill Creek.

EDF - is an index for estimating soil surface moisture storage capacity. The initial value for Little Mill Creek was 1.0.

EF is a factor relating infiltration rates to evaporation rates to provide a seasonal adjustment and account for more rapid infiltration rate recovery during warmer periods. A value of 1.0 was initially selected for Little Mill Creek.

EMIN is the minimum value of EN, a factor varying infiltration by season. A range of between 0.1 and 1.0 has been suggested. An initial value of 0.5 was selected for Little Mill Creek.

GWS is the current value of the groundwater slope index in inches. A range of initial values of between 0.15 and 0.25 has been suggested.

KV24 is a daily baseflow recession adjustment factor used to provide a curvilinear base-flow recession. An initial value of 1.0 is suggested for KV24.

LZS is the current soil moisture storage in inches. This represents the volume of water stored in the lower zone (between the groundwater table and the soil surface). It is suggested that a rough estimate be used for the initial run and the value returned by the model be used for further adjustment.

LZSN is a soil profile moisture storage index, in inches, which approximately equals the volume of water that may be stored in the soil between the ground surface and watertable, but which will also drain freely by gravity. Guidelines by Crawford and Linsley (1966) for estimating initial values of LZSN are as follows:

For Seasonal Rainfall

LZSN = 4 + 1/2 (Mean Annual Rainfall)

For Uniform Rainfall

LZSN = 4 + 1/8 (Mean Annual Rainfall)

MAXRAT - is a variable which determines the timing of the melt from the snowpack. It is important to have MAXRAT high enough to allow some melting but low enough that all meltwater will not refreeze. A value of 0.0001 was found for Little Mill Creek.

SGW - is the groundwater storage increment, in inches, that reflects fluctuation in volume. A value of 0.1 was used for Little Mill Creek.

ASSIGNED INPUT PARAMETERS

The values of the input parameters in this group are obtained from records, assigned,depending on the purpose of the simulation, obtained from tables, or assumed based on the knowledge of the hydrologic processes and watershed characteristics. The thirty parameters in this group are discussed below:

ALANG- is the total daily solar radiation in Langleys per day; it is obtained from the short + long wave radiation onto the snowpack.

B - is an empirical constant, estimated to be 0.0032, for condensation.

DKN - is the program control array; its value is set equal to 1 or 0 depending on the input data available and output desired.

E - is pan evaporation for a one-day or ten-day average depending upon control option 3. Pan evaporation data may be obtained from a U.S. Weather Bureau station.

EPXM - is the maximum interception rate for a dry watershed in inches per hour. It can be estimated from a range of values presented in a table by Crawford and Linsley (1966).

FLO - is the recorded daily average streamflow in cubic feet per second; the data is usually obtained from Water Supply Papers by the U. S. Geological Survey, State Water Resource Commissions, and field monitoring program.

GM - is the snow melt in inches per day due to conduction from the ground. The range is between 0.00 and 0.02.

K3 - is a soil evaporation parameter which measures the rate of loss through evapotranspiration from lower zone soil moisture. A table of values is given by Crawford and Linsley (1966).

K24L - is a parameter indicating the fraction of moisture lost or diverted from active groundwater storage through subsurface flow across the drainage basin boundary. It also represents that portion of inflow to groundwater that percolates to deep or inactive groundwater. K24L can often be assumed to be zero, since these losses are small compared to rainfall and runoff; it can also be estimated from observed changes in deep groundwater levels.

K24EL - is the fraction of the total watershed area in which evapotranspiration from groundwater storage is assumed to occur at the potential rate. K24EL is zero unless a significant quantity of vegetation draws from below the water table.

LIQS - is the liquid-water-holding capacity of snow. This number is largely dependent upon the snow density and is assumed to be 5 per cent of the water equivalent of snow in Ohio.

LIQW - is the liquid water content of snow. It was assumed to be 0.10.

MINH - Hourly flows are printed if flow exceeds this value; therefore, MINH (cfs) will vary depending on the purpose of the simulation.

NN - is the average Manning roughness coefficient for overland flow on soil surface. Its value is usually estimated from published tables.

NNU - is the average Manning roughness coefficient for overland flow on impervious surfaces. It is estimated from the same sources used for NN.

P1 - is the hourly recorded rainfall array in inches. If there is no rainfall for a twelve hour period, no input card is required.

PREC - is the storage gage daily (24 hour period) rainfall total in inches.

QTI - is the initial thermal quality of snow after it has fallen. This number has to be determined through snow measurements; these measurements were not available and so a nominal average value of 0.90 was assigned to each snowstorm.

RFC - is a parameter for nonlinear routing. The subroutine "RTVARY" in which it appears is not operational in the O.S.U. Version of the model, therefore any non-zero number may be used for RFC.

SCF - is the snow correction factor. If, for example, the simulated flows are continually lower than the recorded flows during the winter months then it may be suspected that snow precipitation measurements are incorrect. To adjust the records the snow input can be multiplied by SCF.

SDIV - is the daily average streamflow diverted into (+) or out of (-) the basin. For the Little Mill Creek watershed daily flow diversions were considered to be zero.

TDEW - is an array of 15 dewpoint temperatures which begin at 30°F and increase by fives to 100°F.

TDPT - is recorded average dewpoint temperature in °F.

TINC - is the selected routing interval in minutes.

TMAX - is an array of daily maximum temperature in °F.

TMIN - is an array of daily minimum temperature in °F.

UZS - is the current volume, in inches, of soil surface moisture as interception and depression storage. UZS is normally zero unless there is precipitation during the last few days of September, causing the model to start the water year with some value.

VAP - is an array of vapor pressures corresponding to TDEW.

VW - is an array of total daily wind movement in miles per day.

YEAR - is the recorded annual streamflow in acre feet for the water year.

CONSTANT INPUT PARAMETERS

Some of the input parameters are constants such as time of day, year, plot titles, or identification numbers. These constants are determined by the user depending on the available data and his output requirements. The thirty-nine parameters in this group are defined below:

AXISX - is the length (inches) of abscissa for plotting hydrographs.

AXISY - is the length (inches) orordinate for plotting hydrographs.

CN - indicates ante or meridiem, 1 = A. M. ; 2 = P. M.

DAY - is the day of the month

DD13 - is the number of days (24 hour periods) of storage-gage input rainfall.

DD15 - is the day of the year for the corresponding storage gage rainfall. January 1 through December 31 corresponds to 1 through 365 on the data card. February 29 equals 366.

DDELDR- is the number of cubic feet per second per inch of ordinate used in plotting the arithmetic hydrograph.

DDX - is the label of abscissa for individual storm plot.

DDY - is the label of ordinate for individual storm plot.

DDYR1 - Last two digits of the first year in the water year.

DDYR2 - Last two digits of the last year in the water year.

DELDR - The number of cubic feet per second per inch of ordinate used in plotting the logarithmic hydrograph.

DELDR1 - The spacing between tic marks for the ordinate of the logarithmic hydrograph (inches).

DELDR2 - The spacing between tic marks for the ordinate of the arithmetic hydrograph (inches)

DL - The dash length used in plotting the synthesized hydrographs (inches).

DRORG - The numeric label for the minimum value of the ordinate at the axis origin for the logarithmic hydrograph.

DRRORG - The numeric label for minimum value of the ordinate axis origin for the arithmetic hydrograph.

INUM - Number of elapsed days for which detailed output is requested.

IOUT - Day number of the calendar year from the beginning of a storm for which detailed output is requested.

MO - Month of the year.

QQO - Alphanumeric input to identify the stream gage.

QQQ - Alphanumeric input to entitle the computer output.

QQY - Alphanumeric data for labeling the ordinate of the runoff hydrograph. This should be changed for each water year and watershed.

SGRT - The hour of the day at which the storage gage rainfall is always read (0 to 24).

SL - The space length used in plotting the synthesized hydrograph (inches).

ST - The number assigned to recording rain gage by U. S. Weather Bureau or some other identification number.

SYM - Title of abscissa for runoff hydrograph.

XAX - The length of abscissa for the individual storm plot.

XORG - Numeric label for the minimum value of the abscissa at the axis origin for the individual storm plot.

XTIC - The spacing between tic marks for the abscissa of the detailed storm plot in inches.

XUNIT - The number of hours per inch of abscissa used in plotting the individual storm.

YAX - The length of ordinate for the detailed storm plot in inches.

YORG - The numeric label for the minimum value of the ordinate at the axis origin for the detailed plot.

YR - The last two digits of calendar year.

YRDET - Number of years of data being analyzed.

YTIC - The spacing between tic marks for the ordinate of the storm plot in inches.

YUNIT - The number of cubic feet per second per inch of ordinate used in the selected storm plot.

ZTIC - The spacing between tic marks for the ordinate of the rainfall hyetograph plot in inches.

ZUNIT - The number of ordinate used in the rainfall hyetograph.

SENSITIVITY STUDY

To determine the best estimate of basic input parameters for the agricultural watersheds at the North Appalachian Experimental Watershed, a sensitivity study was performed. Watershed 97, the largest of the six watersheds investigated, was used in the sensitivity study. Three values were assigned to each parameter to ascertain its response in the model; three proved sufficient to define the behavior of the equations.

The parameters chosen for the study, LZSN, CB, EDF, K3, EF, EMIN, CX, EPXM, CY, KK24, IRC, and GWS, deal principally with the moisture balance of the watersheds. They are not directly identifiable from the geomorphology of the area. The parameters were varied with the prime objective of balancing the runoff yield for the years of record with secondary considerations given to the daily soil moisture values, hydrograph peak values, hydrograph recession flows, and the daily correlation coefficient.

SOIL MOISTURE STORAGE CAPACITY INDEX AND THE RATIO LZS/LZSN

LZSN is the soil moisture storage capacity index in inches which is an approximation of the volume of water that may be contained in the soil between the ground surface and the water table. The ratio of the current soil moisture (LZS) and the soil moisture storage capacity (LZSN) controls the rates of infiltration, evapotranspiration, and percolation of groundwater.

Table 6 shows the results of the study for three values of LZSN and three values of the ratio LZS/LZSN. The model's performance for the first two years was not considered in the final selection of LZSN since the soil moisture tables showed that the model had not reached equilibrium in its soil moisture balance until the third year. Referring to Table 6, the following can be deduced: The actual ratio of LZS/LZSN returned by the model became more consistent as the value of LZSN was increased. The best ratio seems to fall in the range 0.7 to 0.8. The fluctuation in the soil moisture values increased, but with less severity, as LZSN was increased. The average behavior of the soil moisture fluctuation (from dry summer conditions to wet winter conditions) seems to be about 4.4 inches.

Table 6. Results of Soil Moisture Study

LZSN (inches)	Year	LZS/LZSN Returned by Model	High Soil Moisture Value Returned by Model (inches)			Largest Fluctuation in Soil Moisture (inches)			Yield (%) Over (+) and Under (-) Synthesized		
5.0	1960-61	0.64	5.6	5.6	5.6	3.4	3.4	3.4	- 3.8	- 3.8	- 3.8
	1961-62	0.44	5.9	5.9	5.9	3.7	3.7	3.7	+ 1.2	+ 1.2	+ 1.2
	1962-63	0.76	5.8	5.8	5.8	4.4	4.4	4.4	+24.5	+24.5	+24.5
15.0	1960-61	0.80	14.5	14.5	14.6	4.2	4.2	4.3	- 4.5	- 3.9	- 3.5
	1961-62	0.69	14.4	14.4	14.4	4.1	4.1	4.1	- 1.7	- 1.5	- 1.4
	1962-63	0.72	14.0	14.0	14.0	5.5	5.5	5.5	+14.9	+15.0	+15.0
25.0	1960-61	0.82	22.7	23.2	23.5	4.2	4.4	4.4	- 7.3	- 4.5	- 2.5
	1961-62	0.75	22.7	22.8	23.0	4.2	4.0	4.1	- 0.8	+ 0.8	+ 2.1
	1962-63	0.75	21.9	22.0	22.1	5.6	5.6	5.7	+13.6	+14.1	+14.5
LZS/LZSN at the Start of Water-Year 1958-59			0.5	0.8	1.0	0.5	0.8	1.0	0.5	0.8	1.0

The high soil moisture values for the years are greater than the designated LZSN until LZSN becomes greater than 5.0 inches. As LZSN is increased, the yields decrease quite considerably for the lower ratios of LZS/LZSN. This is due to the increased soil depth having more recharge (filling up) capacity with a smaller initial value of LZS. This trend is not established for the higher ratios of LZS/LZSN. The higher values of LZSN gave less yield, were relatively more sensitive, but in general all values were rather insensitive to the variance of LZS/LZSN.

In trying to estimate the proper value of LZSN it seems that 5.0 inches is too small as the 1962-63 water-year is considerably (25%) oversynthesized. Also, from the above discussion, the LZS/LZSN ratio of 0.5 does not seem large enough. These conditions suggest a choice of LZSN between 15.0 and 25.0 inches with an appropriate ratio of LZS/LZSN. From observing the soil moisture change in the model and an estimation of the field conditions, an LZSN value of 20.0 inches of moisture was adopted with an initial value of LZS of 15.0 inches for Watershed 97.

INFILTRATION INDEX

CB is the infiltration index that controls the rate of infiltration. It functions in the model's formula for peak infiltration rate:

$$D4F = \frac{0.25 * EN * C2 * CB}{2.0 ** LNRATM}$$

In general, an increase of CB had a very significant effect of decreasing (4 to 13%) the simulated yield. Hydrograph peaks were lowered for the entire year due to the increase in infiltration. Along with this, the recession flows, especially for interflow, were increased. An example of this response to CB is shown in Figure 19.

Initially, CB was taken as 1.5 and used for quite a few simulation runs. This had a very important effect of lowering the hydrograph peaks and raising the interflow recessions as anticipated. However, this value was allocating too much of the water into groundwater as indicated by the undersynthesized results obtained.

At this time it was suspected that EDF might be readjusted upwards (0.4 to 0.7) to attenuate the summer peaks. Then CB was decreased (1.5 to 0.85) to pick-up yields in general. A preferred estimate of CB seems to fall within the range 0.75 to 0.90 with 0.85 adopted for the continuation of the study.

SOIL SURFACE MOISTURE STORAGE CAPACITY INDEX

EDF is an index for estimating the soil surface moisture storage capacity which has the primary purpose of varying the seasonal storage capacity to account for increases in the soil surface moisture caused by summer vegetation. EDF operates in the program equation:

UZSN = EDF * SEP + CX * EXP (-2.7 * LZS/LZSN)

When EDF is increased there is more water held on or immediately below the soil surface to be evaporated, hence less water contributing to runoff. This was evidenced by observing that the daily values of UZSN were significantly increased for an increase in EDF. Figure 20 shows how UZSN varies with different values of EDF over a water-year.

EDF is best determined by trial and adjustment. In general, for the study period, as the value of EDF was increased the yield volumes were somewhat

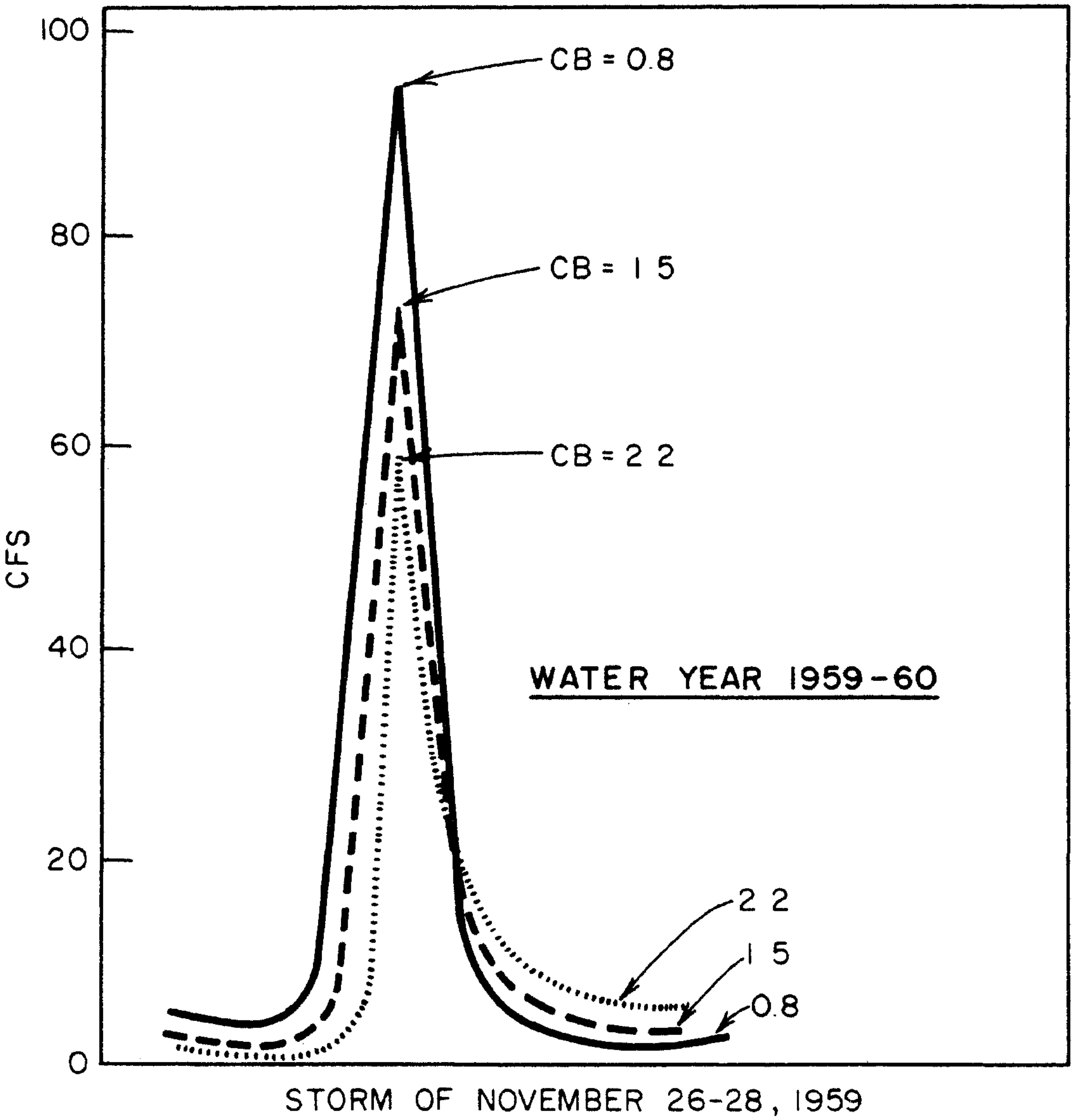


FIGURE 19. EXAMPLE OF MODEL RESPONSE TO VARIATION IN CB

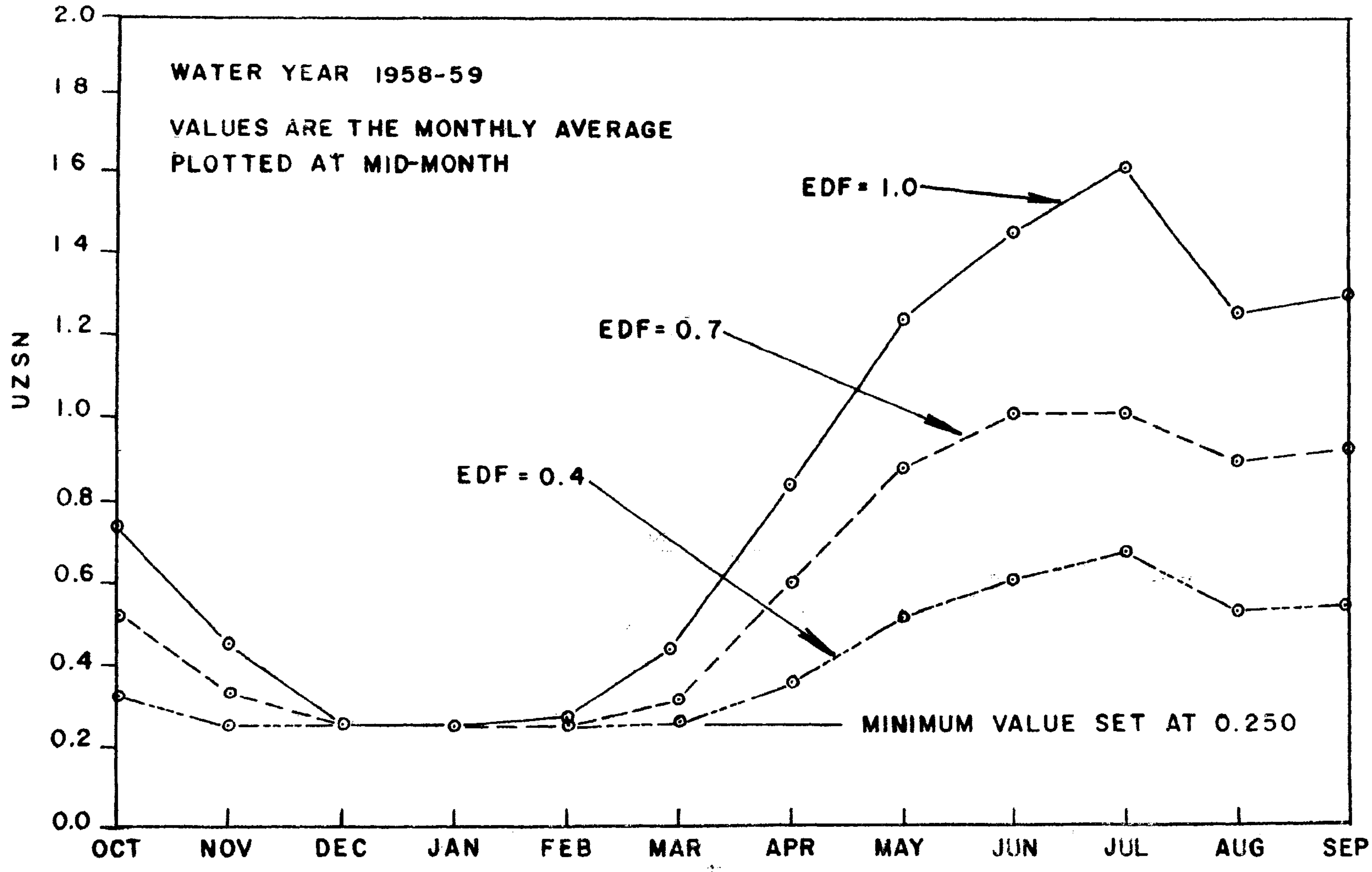


FIGURE 20. SEASONAL VARIATION OF UZSN FOR DIFFERENT VALUES OF EDF

(6 to 15%) decreased. Also, the synthesized winter peaks and recession flows were hardly changed, but from early spring through the summer, the peaks and recessions were lowered quite significantly. Figure 21 is an example of these effects for summer storms.

This study indicated that 0.4 was too small because the summer peaks were extremely oversynthesized. A better value seems to be in the range 0.7 to 1.0. The value 0.85 was adopted for simulation of Little Mill Creek as this gives a more realistic synthesization for the summer activity.

SOIL EVAPORATION PARAMETER

K3 is a soil evaporation parameter that measures the moisture lost through evapotranspiration from the lower zone soil moisture. Clarke (1968) and Crawford and Linsley (1966) suggest a range of values for K3 from 0.2 to 0.3 depending upon the watershed cover. Increased values of K3 will deplete soil moisture storage by increased evapotranspiration which will reduce storm peaks and lower the yield volumes considerably.

It was found that the model was quite sensitive to changes in K3. After simulation runs with different values of K3 ranging from 0.2 to 0.4 for the five year study period, the value 0.2 was adopted for further work.

INFILTRATION-EVAPORATION RATE FACTOR

EF is a factor relating infiltration and evaporation rates. Its major influence is to adjust summer infiltration rates. It is an exponent in the following equation for EN which greatly effects the peak infiltration rate:

$$EN = \left[\frac{SSEP}{ISEP} \right]^{EF}$$

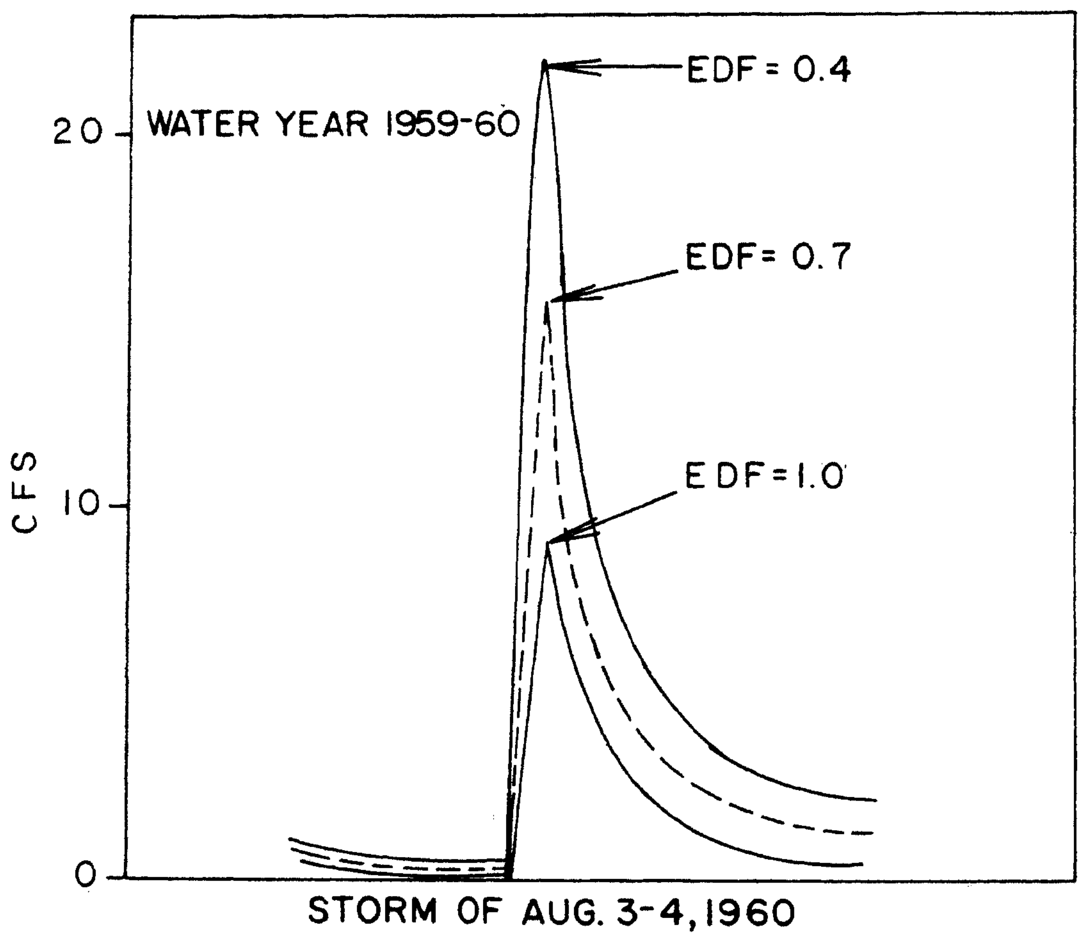


FIGURE 21. EXAMPLE OF MODEL RESPONSE TO VARIATIONS IN EDF

Figure 22 shows the seasonal variation of EN for several values of EF. An increase of EF will increase the infiltration rate in the summer and decrease the summer peaks. In general, the yield volume will decrease because the water is shifted from direct runoff to interflow and base flow. Increasing EF will keep the water on and in the watershed longer and therefore increase the opportunity for evapotranspiration. Figure 22 shows that EF had little effect on the winter storms due to a preset minimum value of EN.

For the study area the climate is such that the major portion of the precipitation that occurs in the summer season is due to high intensity thundershowers of short duration that cover only a small area. Hence, there was not a major variation in yield for changes in EF. However, summer peaks were better simulated for an adopted value of EF equal to 4.0.

MINIMUM VALUE OF EN

Figure 22 shows how EMIN, the minimum value of EN (set at 0.33), responds during the wet months generally occurring from October through April.

Figure 23 shows how hydrograph peaks and recession flows react using a range (0.1 to 1.0) of EMIN for a December storm. In general, the increase of EMIN in this range caused the yield volumes to drop by an average of 11 percent, the winter peaks to be greatly reduced, and a soil moisture accretion of 2 to 3 inches. Also, increasing EMIN put more water into groundwater which could not only be seen by examining the soil moisture output table values, but by the increase of the recession flows, particularly the interflow. Furthermore, it was noticed that at the lower EMIN value the hydrograph is more responsive

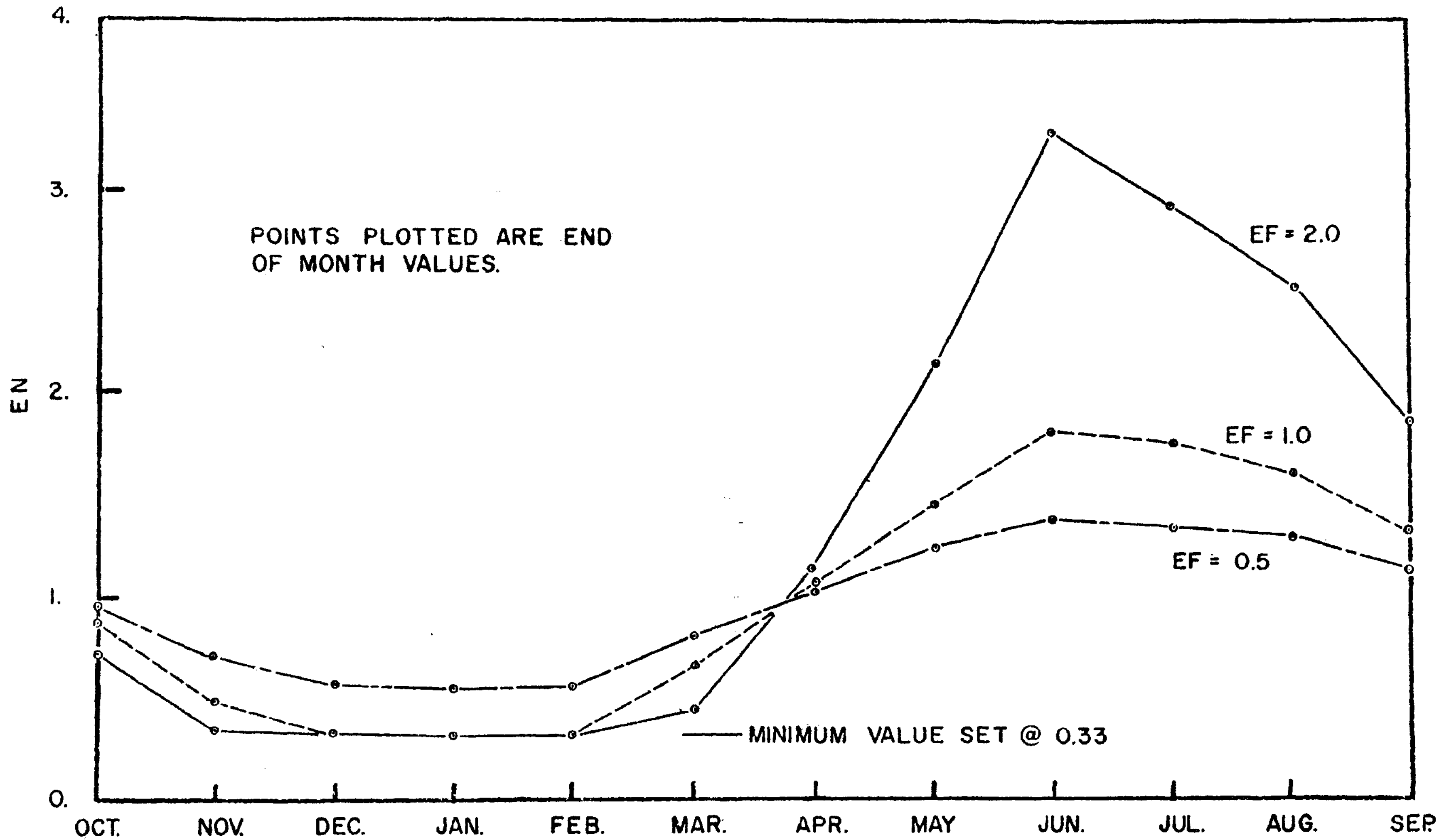


FIGURE 22. SEASONAL VARIATION OF EN FOR LITTLE MILL CREEK DATA

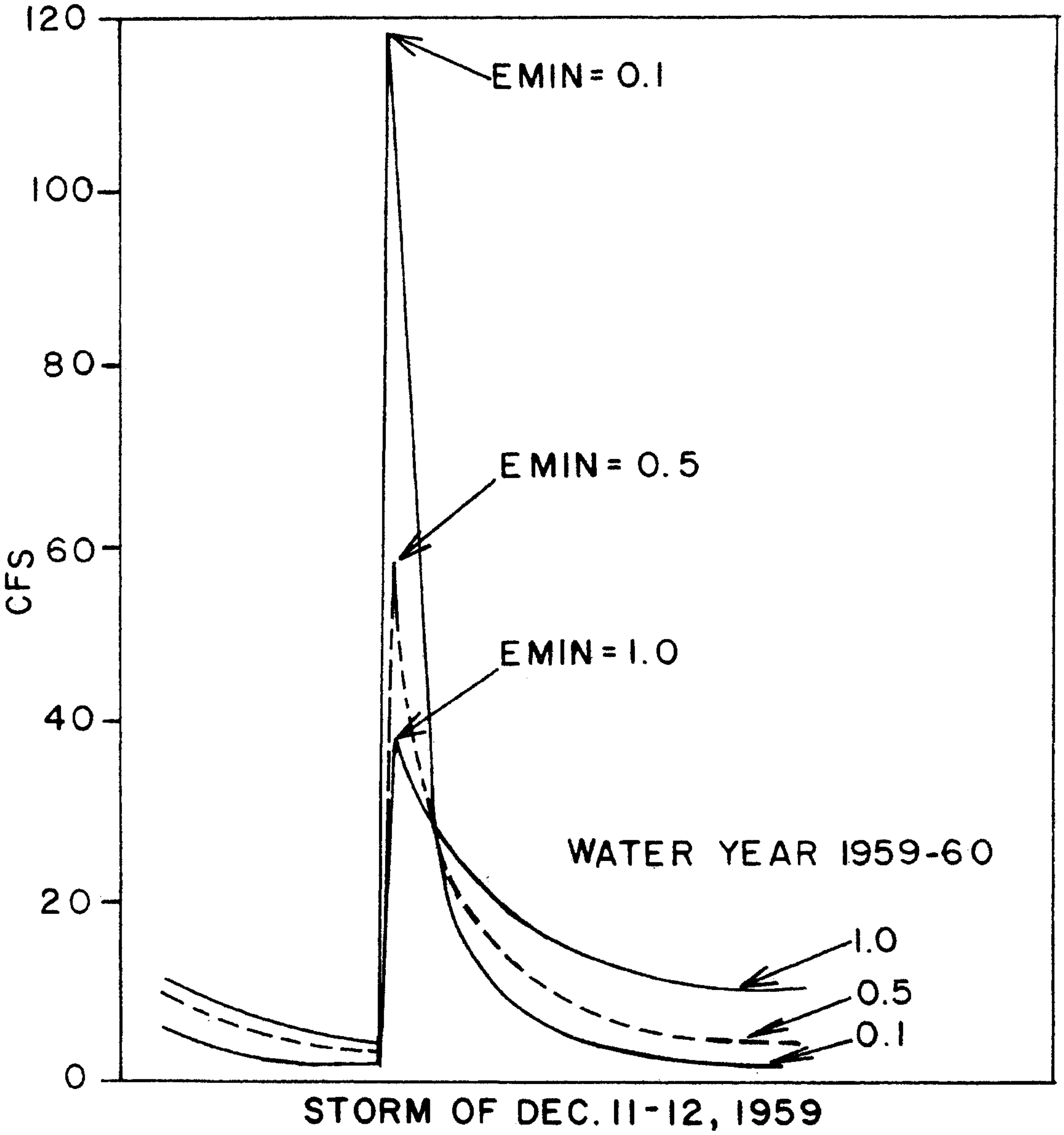


FIGURE 23. EXAMPLE OF MODEL RESPONSE TO VARIATIONS IN EMIN

to slight rainfalls in the winter months as evidenced by a saw-tooth effect on the hydrograph recessions.

An EMIN of 1.0 decreased the winter peaks too much and 0.1 made the peaks greatly oversynthesized. An EMIN of 0.5 will be taken as the best approximation because this value best fits the synthesized peaks to the recorded peaks.

INTERCEPTION AND DEPRESSION STORAGE INDEX

CX is an index for estimating the capacity of the soil surface to hold water as interception and depression storage. In general, the quantity of water stored at any given time will be less than the storage capacity except for temporary periods during major storms when the model permits the storage capacity to be exceeded. For an increase in CX, there will be more water held at the soil surface zone with more opportunity for evaporation and less for runoff.

CX functions in the equation for the nominal storage capacity of the upper zone:

$$UZSN = EDF * SEP + CX * EXP\ (-2.7 * LZS/LZSN)$$

Examination and knowledge of the equation indicates that CX has a relatively minor role and is used as a fine-tuning adjustment for the upper zone. For an increase of CS (0.4 to 1.4), yield volumes were decreased by 2 percent, peaks were moderately lowered, and recession flows remained approximately the same. The value of 0.4 was held as the best approximation for CX.

DRY WATERSHED MAXIMUM INTERCEPTION RATE

EPXM is the maximum interception rate in inches per hour for a watershed in a dry condition. It is dependent upon the type and density of vegetative cover. For an increase (0.1 to 1.0) of EPXM, yield volumes were decreased about 3 percent and little rises in the recession flows for some storms were attenuated. This can be explained using the logic that with an increase of EPXM there will be an increased rate of interception with more water being retained on the vegetative surface, hence, less water traveling to the soil.

Also, for the above mentioned increase, synthesized peaks were very slightly reduced, while recession flows remained unaffected. Considering the guidelines given by Crawford and Linsley (1966) for approximating EPXM, 1.0 seems too large. However, it should be kept in mind that EPXM represents an average value over the watershed and local areas could be such that this value holds. Further simulation runs for other parameters were made with EPXM equal to 0.5. This value was later reduced to 0.15 and adopted as the best approximation of EPXM for further work on agricultural watersheds.

INTERFLOW PARAMETER

CY is an interflow index controlling the quantity of moisture entering interflow. Increasing CY should allocate more water to interflow and decrease RX, the current direct runoff. Clarke (1968) gives a range from 1.0 to 4.5 inches from his sensitivity study for CY.

Increasing CY from 1.0 to 4.0 caused a slight increase in the synthesized hydrograph recession flows. Upon checking the daily values of SINT, the variable used to sum synthesized daily interflows, a slight increase in SINT was detected, but no appreciable change was observed in the hydrographs. Also, there was no noteworthy fluctuation in the daily soil moisture values. The model seems rather insensitive to an increase in CY. Hence, the choice for CY could be set anywhere in the range (1.0 to 4.0) with the value 3.0 adopted for further study.

DAILY BASEFLOW RECESSION CONSTANT

KK24 is the daily base flow recession constant estimated by graphical hydrograph separation techniques for selected storms on the Little Mill Creek Watershed. Our initial study found KK24 values to range from 0.75 to 0.98.

Figure 24, a March storm hydrograph, shows the effect of decreasing KK24 from 0.95 to 0.75. It can be observed from this figure that reducing KK24 caused the interflow recessions to be lifted, the base flow recessions to be lowered, and the synthesized peak flows to be increased. Also the yield volumes were increased slightly. The daily values of SGW, the groundwater moisture storage, were dropped significantly with the decrease of KK24 which accounts for the decrease in base flow, GWF, calculated with the following model equation:

$$GWF = SGW * LKK4 * (1.0 + LKV4 * GWS)$$

Because the decreased value of KK24 had an adverse effect on the base flow, the higher value 0.95 was adopted.

DAILY INTERFLOW RECESSION CONSTANT

IRC is the daily interflow recession constant that may be estimated by graphical techniques for hydrograph analysis. A decrease (0.75 to 0.30) of IRC produced no significant change in the yield volume and soil moisture. Minor effects

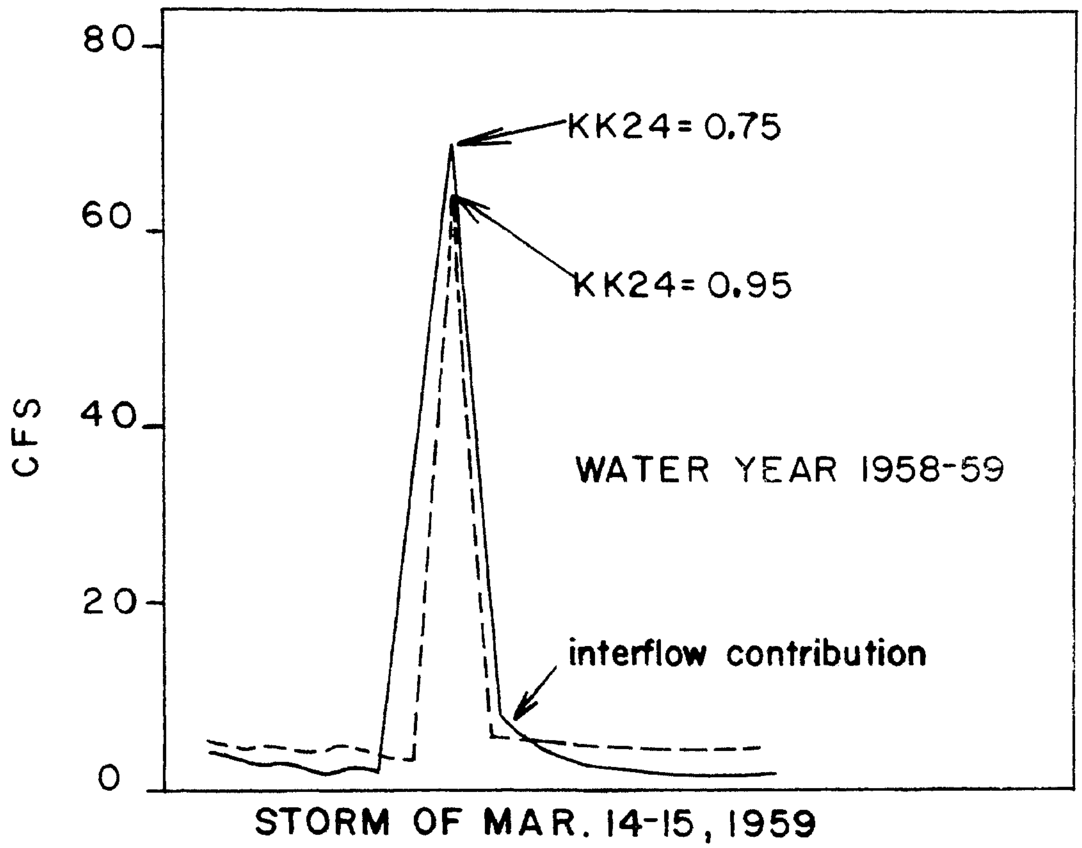


FIGURE 24. EXAMPLE OF MODEL RESPONSE TO VARIATIONS IN KK24

of the decrease include a slight rise of some recession flows and a backward time shift for a few peaks.

Since the lowering of IRC produced no significant results, 0.75 was adopted for future study.

GROUNDWATER SLOPE INDEX

GWS is the value of the groundwater slope index and is an indication of the antecedent moisture conditions of the watershed. GWS operates in the following computer statement for GWF, groundwater flow:

GWF = SGW * LKK4 * (1.0 + LKV4 * GWS)

As an initial estimate, SGWL (= 0.1), was used as an initial value of GWS. From observing the daily values of GWS for the five-year period of study, a better starting value seems to be in the range 0.15 to 0.25. The value 0.20 was taken for continued work.

ROUTING INTERVAL

By introducing the variable FRAC, which represents the selected routing interval expressed as a fraction of an hour, the previously fixed 15-minute routing interval was made variable. The model was applied to three watersheds, 94, 10, and 5, and in addition to the 15-minute routing interval, five and three-minute intervals were also investigated.

The results are displayed as a plot of recorded streamflow and the various simulated hydrographs obtained by varying the routing time increment. An attempt was made to include only the simulated storms, being neither the worst nor the best, which could also be found in the Coshocton 50-select storm record.

The trends, which can be observed in Figures 25 and 26 (streamflow hydrographs for Watershed 94 for the selected storms), obtained by decreasing the previously fixed 15-minute routing interval down to 5 and 3 minutes are the following:

1. The peak is shifted earlier in time;
2. The synthesized peak flows are increased;
3. The baseflow and interflow recession curves is lowered;
4. The storm yield volumes are not noticeably changed.

Although the time increment changes varied the individual storm hydrographs, the yields and average daily flows are approximately unaffected.

The variability of the rainfall patterns from storm to storm is the principal cause of random departures between synthesized and recorded flows. This is demonstrated by examination of short-term rainfall records within the basin during particular storms. The model attenuates the peak flows due to the averaging of rainfall over the hour instead of reading the flash storms as they actually occur.

An inconsistency in peak simulation on these three subwatersheds was also noted, which indicates that the same set of input parameters do not apply to all the watersheds. The hydrographs of Watershed 94 display good simulation. However, the peak flows for Watersheds 10 and 5 were respectively under and oversynthesized.

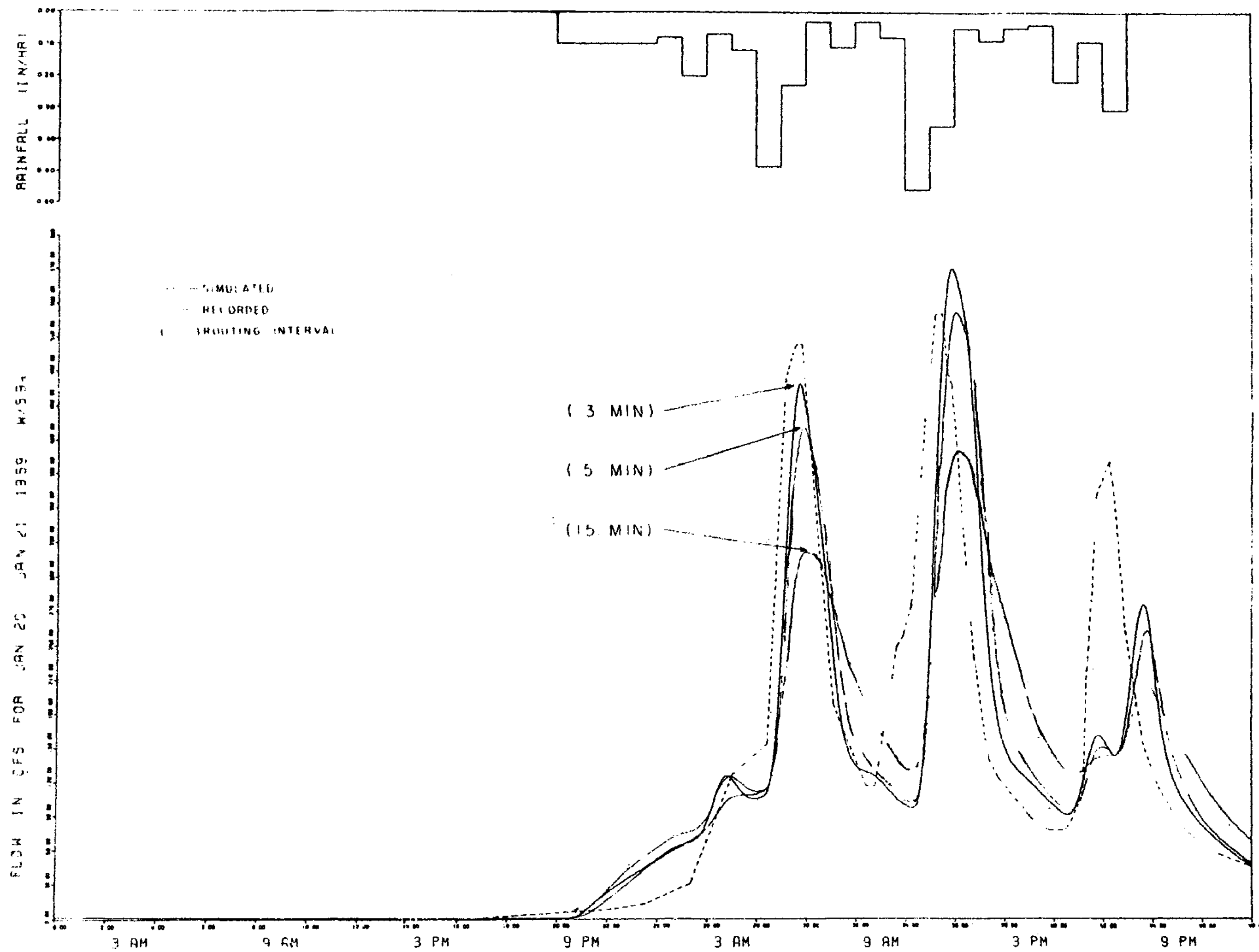


FIGURE 25. SIMULATED AND RECORDED STORM HYDROGRAPHS FOR WATERSHED 94 FOR JANUARY 20 - 21, 1959

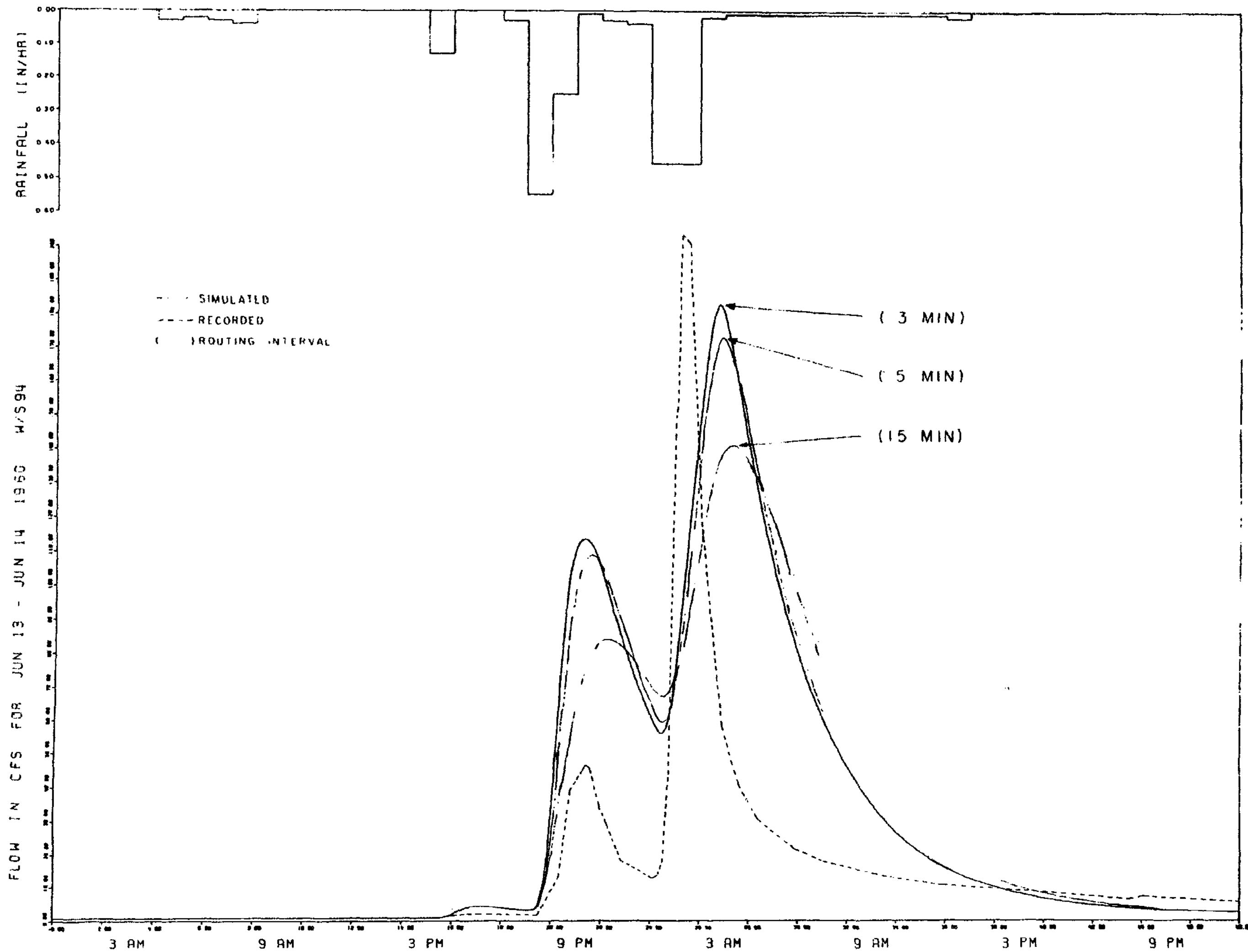


FIGURE 26. SIMULATED AND RECORDED STORM HYDROGRAPHS FOR WATERSHED 94 FOR JUNE 13 - 14, 1960

SUMMARY OF SENSITIVITY STUDY

In summarizing the sensitivity study performed, Table 7 was constructed from the results. It shows the relative effect of the changes in the selected parameters on the more salient features in the simulation. It can be used as a guide in adjusting the values for the basic input parameters.

FINAL INPUT PARAMETERS

The final input parameters used in the simulation are shown in Table 8. Table 9a shows the time-area histogram data for the six watersheds investigated and for a 15-minute routing interval. The routing intervals of 3, 5, and 15 minutes were applied to watersheds 94, 10, and 5; the corresponding time-area histogram data are shown in Table 9b.

Table 7. Summary of Results of the Sensitivity Study

Key: ↑ Increased; ↓ Decreased; --- Not Affected; * Slightly; ** Moderately; *** Significantly; W - Winter; S - Summer

Selected Input		Simulation Feature								
			Peaks		Interflow Recessions		Base Flow Recessions		Soil Moisture	
Parameter	Parameter Change	Yield	W	S	W	S	W	S	W	S
LZSN	↑	*** ↓	** ↓	** ↓	** ↓	* ↓	** ↓	* ↓	*** ↑	*** ↑
CB	↑	*** ↓	*** ↓	*** ↓	** ↑	** ↑	* ↑	* ↑	*** ↑	*** ↑
EDF	↑	*** ↓	-----	*** ↓	-----	*** ↓	-----	** ↓	-----	* ↑
K3	↑	*** ↓	** ↓	** ↓	* ↓	* ↓	* ↓	* ↓	* ↓	* ↓
EF	↑	* ↓	-----	*** ↓	-----	** ↑	-----	** ↑	-----	* ↑
EMIN	↑	*** ↓	*** ↓	-----	** ↑	-----	* ↑	-----	** ↑	-----
CX	↑	* ↓	* ↓	* ↓	-----	-----	-----	-----	-----	-----
EPXM	↑	* ↓	* ↓	* ↓	-----	-----	-----	-----	-----	-----
CY	↑	-----	-----	-----	-----	-----	-----	-----	-----	-----
KK24	↑	* ↓	** ∣	** ↓	** ↓	** ↓	** ↑	** ↑	-----	-----
IRC	↑	-----	* ∣	* ↓	* ↓	* ↓	* ↓	* ↓	-----	-----
GWS	↑	-----	-----	-----	-----	-----	-----	-----	-----	-----

Table 8. Final Input Parameters for Little Mill Creek Watersheds Investigated

Model Parameters	Parameter Values					
	W/S 97	W/S 95	W/S 94	W/S 92	W/S S	W/S 10
	Measurable Parameters					
A	0.0	0.0	0.0	0.0	0.0	0.0
AREA	7.16	4.02	2.37	1.44	0.55	0.19
CHCAP	800.0	800.0	800.0	800.0	800.0	800.0
COE	0.00177	0.00177	0.00177	0.00177	0.00177	0.00177
ETL	0.0	0.0	0.0	0.0	0.0	0.0
IRC	0.001	0.001	0.001	0.001	0.001	0.001
KI	1.0	1.0	1.0	1.0	1.0	1.0
KK24	0.95	0.95	0.95	0.95	0.95	0.95
KSC	0.85	0.85	0.85	0.85	0.85	0.85
KSF	0.94	0.94	0.94	0.94	0.94	0.94
L	470.0	525.0	570.0	600.0	463.0	546.0
SS	0.16	0.15	0.132	0.14	0.144	0.145
TAREA						
TCONC						
VOLUME						
WSG						
	Trial and Adjustment Parameters					
CB	0.85	0.85	0.85	0.85	0.85	0.85
CX	0.40	0.40	0.40	0.40	0.40	0.40
CY	3.0	3.0	3.0	3.0	3.0	3.0
EDF	0.85	0.85	0.85	0.85	0.85	0.85
EF	4.0	4.0	4.0	4.0	4.0	4.0
EMIN	0.50	0.50	0.50	0.50	0.50	0.50
GWS	0.20	0.20	0.20	0.20	0.20	0.20
KV24	0.75	0.75	0.75	0.75	0.75	0.75
LZS	15.0	9.6	9.6	9.6	9.6	9.6
LZSN	20.0	12.0	12.0	12.0	12.0	12.0
MAXRAT	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
SGW	0.10	0.10	0.10	0.10	0.10	0.10
	Assigned or Selected Parameters					
B	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032
EXPM	0.15	0.15	0.15	0.15	0.15	0.15
GM						
K3	0.20	0.20	0.20	0.20	0.20	0.20
K24L	0.0	0.0	0.0	0.0	0.0	0.0
K24EL	0.0	0.0	0.0	0.0	0.0	0.0
LIQS						
LIQW	0.10	0.10	0.10	0.10	0.10	0.10
NN	0.37	0.37	0.37	0.37	0.37	0.37
NNU	0.015	0.015	0.015	0.015	0.015	0.015
QTI	0.90	0.90	0.90	0.90	0.90	0.90
RFC	1.5	1.5	1.5	1.5	1.5	1.5
SFC						
UZS	0.0	0.0	0.0	0.0	0.0	0.0

Table 9a. Time-Area Histogram Data For Little Mill Creek Watersheds Investigated (Routing Interval = 15 min.)

Watershed	97	95	94	92	5	10
C[1]	162.0	84.4	59.1	32.0	17.4	13.5
U[2]	165	90	60	30	15	15
Z[3]	11	6	4	2	1	1
Elements of the Time-Area Histogram	0.032	0.062	0.183	0.534	1.000	1.000
	0.058	0.135	0.242	0.466		
	0.072	0.250	0.318			
	0.084	0.220	0.257			
	0.085	0.185				
	0.078	0.148				
	0.103					
	0.152					
	0.136					
	0.111					
	0.089					

1. The calculated time of concentration

2. The 15-minute integer miltiple of calculated time of concentration used by the model

3. The number of elements in the time-area histogram

Table 9b. Time-Area Histogram Data For Three Little Mill Creek Watersheds (Routing Intervals = 3, 5, 15)

Watershed	10			94		
[1]	15			60		
TINC	15	5	3	15	5	3
Z[3]	1	3	5	4	12	20
Time-area elements	1.000	0.142	0.051	0.183	0.004	0.002
		0.398	0.149	0.242	0.014	0.004
		0.460	0.235	0.318	0.028	0.008
			0.290	0.257	0.058	0.020
			0.275		0.183	0.014
					0.104	0.107
					0.073	0.048
					0.089	0.126
					0.158	0.109
					0.237	0.048
					0.048	0.051
					0.004	0.026
						0.060
						0.097
						0.108
						0.147
						0.093
						0.017
						0.004
						0.001

Watershed	5		
[1]	15		
TINC[2]	15	5	
Z[2]	1	3	
Time-area elements	1.000	0.109	0.030
		0.379	0.104
		0.512	0.206
			0.258
			0.442

1. The 15-minute integer multiple of the caluclated time of concentration used by the model
2. Routing interval
3. The number of elements in the time-area histogram

RESULTS AND DISCUSSION

Model Output

BASIC OUTPUT

The model, if no additional output options are called, will provide a basic output of synthesized and recorded data as shown in Figure 27 and discussed below. (corresponds to items on Figure 27.)

1 This table presents the synthesized average daily streamflow rates, in cubic feet per second, for each day of the year.

2 SYN STREAMFLOW - Summation of all the synthesized daily average flow rates, in cubic feet per second, for each month followed by the annual total.

3 TOT SYN VOL - Synthesized monthly and annual totals of runoff in inches over the watershed.

4 INTERFLOW VOL - Synthesized monthly and annual totals of interflow in inches over the watershed.

5 BASE FLOW VOL - Synthesized monthly and annual totals of baseflow in inches over the watershed.

6 ANNUAL SYNTHESIZED STREAMFLOW IN ACRE FEET - The volume of synthesized streamflow runoff from the watershed for the entire water year in acre feet.

7 REC STREAMFLOW - Summation of all the recorded daily average streamflow rates, in cubic feet per second, for each month followed by the annual total.

⟨8⟩ RECORDED VOLUME IN INCHES PER YEAR - Recorded annual total of runoff in inches over the watershed.

⟨9⟩ RECORDED VOLUME IN INCHES PER YEAR FROM NOV. THRU MARCH - Recorded volume, in inches over the watershed, from November through March. This is valuable in studying snowmelt problems.

⟨10⟩ AMOUNT OF SYNTHESIZED SNOW FROM NOV. THRU MARCH IN EQUIVALENT INCHES OF WATER - Valuable in snowmelt analysis.

⟨11⟩ ANNUAL RECORDED STREAMFLOW IN ACRE FEET - The volume of recorded streamflow runoff from the watershed for the entire water year in acre feet.

⟨12⟩ REC PRECIP - Summation of recorded precipitation, in inches, for each month followed by the total for the year.

⟨13⟩ SYN E.T. - NET - Synthesized monthly and annual totals of evapotranspiration in inches.

⟨14⟩ POTENTIAL E.T. - Monthly and annual recorded lake evaporation (potential) in inches.

⟨15⟩ STORAGES

UZS - End of the month values, in inches, of current surface moisture storage.

LZS - End of the month values, in inches, of current soil moisture storage.

SGW - End of the month values, in inches, for the groundwater storage fluctuation.

(16) INDICES

UZSN - End of the month values, in inches, of the soil surface moisture storage index.

GWS - End of the month values, in inches, of the current values of the groundwater slope index.

EN - End of the month values of EN, a factor varying infiltration by season.

(17) BALANCE - An annual moisture balance, in inches, which represents moisture not accounted for within the program.

OPTIONAL OUTPUT

The listing below shows the optional items of output that can be requested through selection of the DKN control options presented in the "Input and Output Chapter."

1. Selected storm details.
2. Infiltration adjustment factor
4. Statistics on modeling success
5. Top events
6. Daily soil moisture status
14. Recorded streamflow values
15. Echo check on input data
16. Logarithmic hydrograph plot
17. Arithmetic hydrograph plot

LITTLE MILL CREEK DATA -VERSION OF FEB. 25,1969 -RAIN GAGE NO. 27

GAGE NUMBER 94, LITTLE MILL CREEK — WATER YEAR 1960-61 — O.S.U. WATERSHED MODEL

	DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
1	1	0.192	0.045	0.741	0.466	0.461	1.766	13.752	1.548	7.056	0.442	0.926	0.146
	2	0.186	0.044	1.081	0.442	0.426	1.633	2.406	1.430	27.747	0.410	1.123	0.141
	3	0.175	0.041	1.117	0.416	0.394	1.509	1.395	1.322	1.672	0.381	1.049	0.140
	4	0.162	0.038	1.081	0.390	0.365	13.933	1.288	1.221	1.174	0.352	0.970	0.130
	5	0.150	0.044	1.017	0.558	0.337	25.053	1.190	1.129	1.085	0.328	0.897	0.120
	6	0.138	0.057	0.945	1.673	0.313	13.235	1.100	1.063	1.003	0.305	0.829	0.111
	7	0.128	0.067	0.879	3.339	0.305	2.277	1.025	1.381	0.927	0.282	0.766	0.102
	8	0.118	0.065	0.815	2.050	0.329	15.354	0.948	19.205	4.625	0.261	0.709	0.095
	9	0.122	0.090	0.755	1.276	0.527	3.565	11.412	13.717	4.652	0.241	0.656	0.088
	10	0.117	0.145	0.698	1.577	0.519	2.190	12.238	1.502	7.004	0.223	0.622	0.081
	11	0.109	0.135	0.646	3.825	0.739	2.030	1.559	1.256	2.071	0.206	0.595	0.075
	12	0.100	0.125	0.597	2.249	1.509	1.879	9.248	1.161	1.856	0.191	0.550	0.069
	13	0.093	0.115	0.553	1.415	3.110	1.975	5.369	1.073	1.716	0.176	0.509	0.064
	14	0.086	0.107	0.516	1.310	1.123	2.166	1.374	0.991	1.651	0.163	0.471	0.059
	15	0.079	0.099	0.486	2.609	0.807	1.642	1.244	2.824	1.536	0.152	0.435	0.055
	16	0.073	0.095	0.452	1.974	0.746	1.515	19.713	2.778	1.415	0.142	0.405	0.051
	17	0.068	0.089	0.424	1.224	1.810	1.400	4.176	0.994	1.308	0.131	0.380	0.047
	18	0.063	0.082	0.510	1.851	7.073	1.356	3.010	1.140	1.209	0.122	0.351	0.043
	19	0.061	0.076	0.471	1.478	2.128	1.890	1.912	1.069	1.117	0.146	0.325	0.040
	20	0.061	0.070	0.381	1.163	1.206	1.282	1.761	0.926	1.032	0.165	0.300	0.037
	21	0.057	0.065	0.354	1.082	1.113	3.199	24.441	0.856	0.954	0.153	0.286	0.034
	22	0.052	0.063	0.329	1.005	2.228	2.325	16.533	0.791	0.882	0.141	0.277	0.032
	23	0.048	0.087	0.305	0.932	3.906	4.117	5.761	0.731	0.823	0.150	0.257	0.029
	24	0.045	0.081	0.282	0.863	1.437	1.626	1.865	0.676	0.766	0.263	0.237	0.027
	25	0.041	0.074	0.539	0.798	43.768	1.719	77.272	0.625	0.708	0.490	0.228	0.028
	26	0.038	0.069	0.737	0.738	61.385	1.499	28.789	0.597	0.655	0.368	0.233	0.027
	27	0.036	0.064	0.553	0.683	2.875	1.385	2.234	0.554	0.605	0.340	0.216	0.025
	28	0.034	0.059	0.485	0.631	1.911	1.280	2.625	0.512	0.560	0.315	0.199	0.023
	29	0.031	0.076	0.453	0.583		1.183	1.924	0.474	0.517	0.782	0.184	0.021
	30	0.029	0.075	0.423	0.539		1.093	1.675	0.438	0.478	0.596	0.171	0.020
	31	0.035		0.438	0.499		1.096		0.416		0.768	0.158	

2	SYN STREAMFLOW	3.	2.	19.	40.	143.	118.	259.	64.	79.	9.	15.	2.	754.	CFSD
3	TOT SYN VOL	0.043	0.037	0.299	0.622	2.242	1.857	4.068	1.010	1.237	0.144	0.240	0.031	11.83	IN/YR
4	INTERFLOW VOL	0.000	0.000	0.011	0.166	1.756	1.026	2.537	0.505	0.680	0.009	0.000	0.000	6.689	IN/YR
5	BASE FLOW VOL	0.043	0.037	0.289	0.456	0.397	0.802	0.746	0.468	0.536	0.135	0.240	0.031	4.182	IN/YR
6	ANNUAL SYNTHESIZED STREAMFLOW IN ACRE FEET													1495.	ACFT
7	REC STREAMFLOW	5.	9.	5.	20.	112.	211.	294.	81.	43.	53.	17.	6.	856.	CFSD
8	RECORDED VOLUME IN INCHES PER YEAR													13.43	IN/YR
9	RECORDED VOLUME IN INCHES PER YEAR FROM NOV. THRU MARCH													5.60	IN/YR
10	AMOUNT OF SYNTHESIZED SNOW FROM NOV. THRU MARCH IN EQUIVALENT INCHES OF WATER													3.25	INCHES
11	ANNUAL RECORDED STREAMFLOW IN ACRE FEET (1698.)													1697.	ACFT
12	REC PRECIP	1.81	1.82	1.60	0.91	3.93	3.54	6.37	2.65	2.97	5.64	2.17	0.95	34.36	IN/YR
13	SYN E.T.-NET	1.834	0.962	0.512	0.569	0.848	1.638	1.809	2.864	3.182	3.431	4.360	2.534	24.543	IN/YR
14	POTENTIAL E.T.	1.981	0.962	0.512	0.569	0.848	1.681	1.809	3.644	4.694	4.502	4.404	3.858	29.464	IN/YR
15	STORAGES-UZS	0.526	1.237	0.373	0.190	0.371	0.264	0.138	0.288	0.0	2.582	0.0	0.0		IN/YR
	LZS	6.770	6.861	7.496	8.059	8.660	8.956	9.478	8.301	7.171	6.624	6.867	5.278		IN/YR
	SGW	0.009	0.014	0.096	0.096	0.367	0.228	0.321	0.117	0.092	0.121	0.030	0.004		IN/YR
16	INDICES-UZSN	0.432	0.253	0.250	0.250	0.290	0.493	0.537	1.040	1.315	1.049	1.133	1.030		
	GWS	0.119	0.071	0.271	0.320	0.645	0.639	0.795	0.471	0.435	0.310	0.185	0.076		
	EN	0.649	0.500	0.500	0.500	0.500	0.500	0.500	2.875	9.789	8.553	8.659	6.598		
17	BALANCE	-0.0766 INCHES													

FIGURE 27. MODEL SIMULATION RESULTS - BASIC OUTPUT

18. Value of internal functions

19. Snowmelt details

20. Arithmetic hydrograph plot for a selected storm

Simulation Results

Numerous computer runs were made throughout this study to test and evaluate the performance of the various modifications made on the model. As examples of what the model is capable of producing, several plots depicting the model's response to the major modification will be presented in the following set of figures. A brief review of the modification and a discussion of the relative improvement achieved by it will accompany the examples.

Additional plotted simulation results for other watersheds are available in the theses listed in the references.

MULTIPLE RECESSION CONSTANTS AND SWAMP AND CRACK STORAGE

To expedite improvement of the interflow and groundwater flow recessions, a separate program to determine hydrograph recession constants was written. This program was designed to solve for multiple recession constants, which are the result of continuous clay stratum occurring in unglaciated, stratified areas of the North Appalachian Plateau. The program is based on Barnes' technique of hydrograph analysis and on the least squares method of curve fitting. After the appropriate recession constants had been determined, a mechanism for introducing them into the model was developed.

The fall season simulation problem was greatly aided by diverting a portion of the runoff to upper zone storage in the form of swamp and marsh storage and soil crack storage. Figure 28 shows simulation plots with and without this modification. Notice the November events.

Modification of the groundwater flow parameters CB, CY, and LZSN, increased the proportion of interflow and groundwater flow while maintaining approximately the same level of yield as before.

As a result of the above changes, a definite improvement was noted. Yield for the water year, daily correlation, interflow and groundwater flow were all generally improved. While recession curves were still not exactly simulated, because of neglecting the effect of intensity and duration of precipitation, they are at present much closer to the recorded flow and further modification will produce little improvement in yield or daily correlation.

TIME INCREMENT CHANGES

To render the model more applicable to small watersheds, the previously fixed fifteen minute routing interval was modified to accommodate a smaller interval. The variable TINC, the selected routing interval in minutes, was introduced to accomplish this formality. TINC may vary from 60 minutes to 1 minute with the following two restrictions: 1) Must be evenly divisible into 60 minutes and 2) Must be evenly divisible into time of concentration.

To expedite this investigation, an option to plot the detail storm hydrograph was introduced to provide a useful tool for studying the model simulation. The comparison between observed and synthesized hydrographs was facilitated by

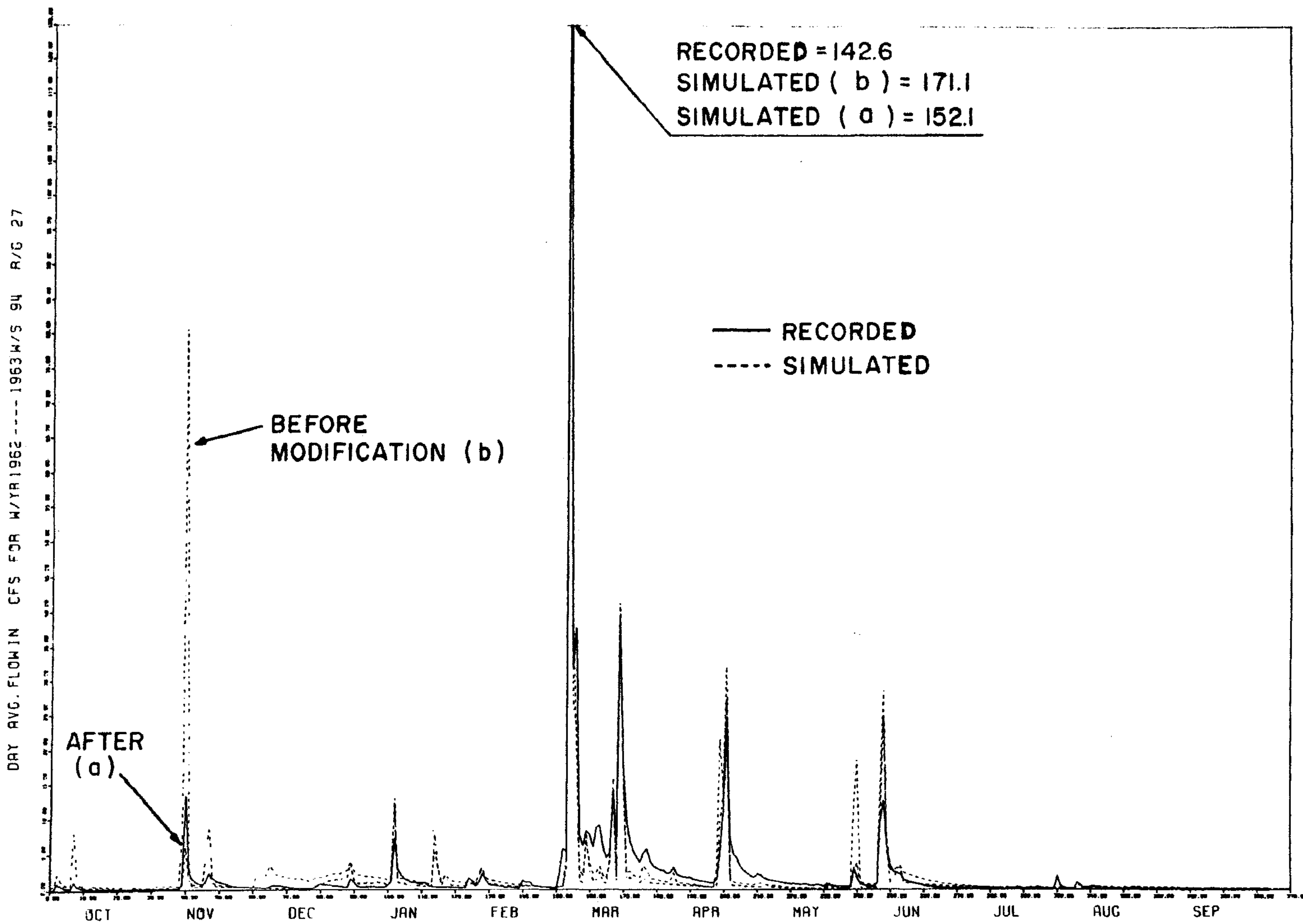


FIGURE 28. HYDROGRAPH COMPARISON FOR WATERSHED 94, WATER YEAR 1963

superimposing these plots. Modifications were introduced to the output control option DKN (1) to permit the selection of one storm for each year of record.

A supplementary program which plots the recorded hydrograph and rainfall hyetograph, was also developed at this time.

Application of the revised model to the three agricultural watersheds, ranging in size from 1520 to 122 acres, for the three select storms shows that an adequate duplication of the recorded storm hydrographs can be obtained. As the time increment is decreased, the synthesized storm peak flows are shifted earlier in time and increased in magnitude, the baseflow and interflow curves are lowered, and the storm yield volumes are not noticeably changed. Simulated hydrograph results are displayed in Figure 29. Additional plots are shown in Figures 25 and 26 presented in an earlier chapter.

SNOWMELT SUBROUTINE

Results of this study show that the snowmelt subroutine is quite workable and will improve the correlation between synthesized and recorded streamflows. After several trial and error computer runs were made to determine the best values for the cold content build-up rate and the initial thermal quality of the snow, a statistical analysis was computed for the Little Mill Creek watersheds. The results showed that both the timing and the quantity of runoff during the snow season had been greatly improved. A few mismatched hydrograph peaks were the result of the unavailability of more extensive data. Figure 30 shows the simulation results with and without the snowmelt subroutine. Attention should be directed to the winter months for evaluating the results. The poorly matched peaks in the fall exist because the swamp and crack storage modification was not included in this run.

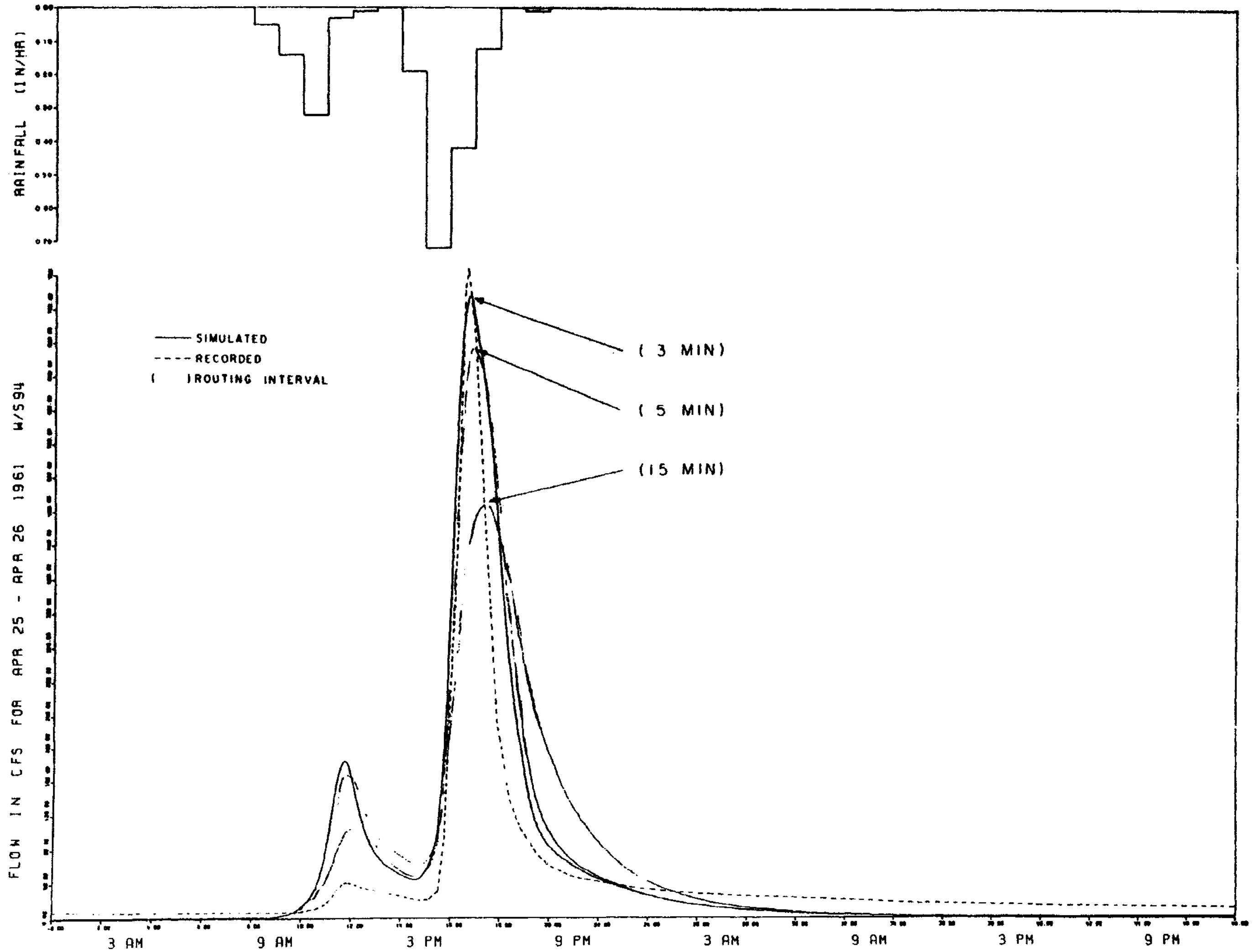


FIGURE 29. SIMULATED AND RECORDED STORM HYDROGRAPHS FOR WATERSHED 94 FOR APRIL 25 - 26, 1961

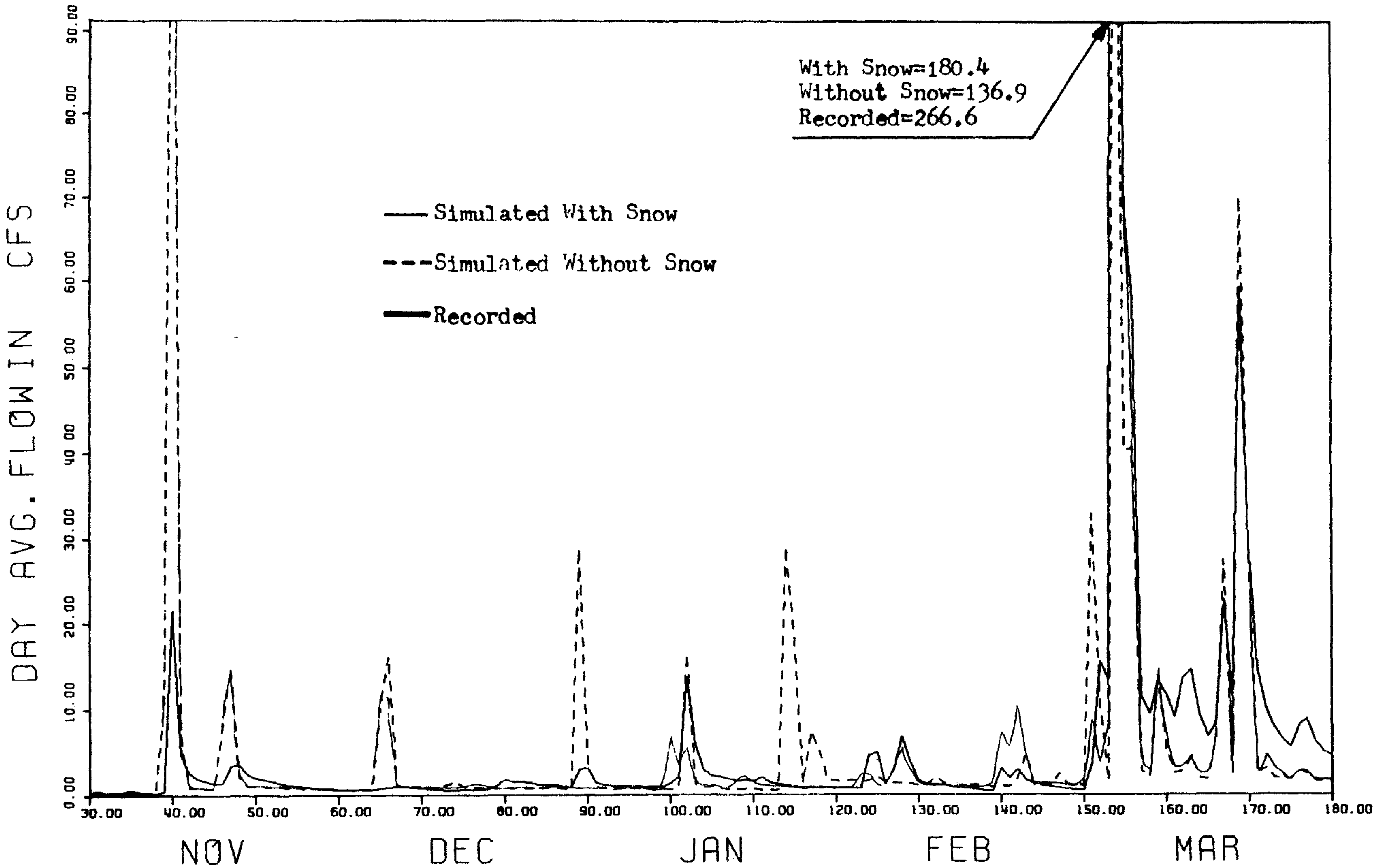


FIGURE 30. SIMULATED AND RECORDED HYDROGRAPHS FOR WATERSHED 95 WITH AND WITHOUT SNOW FOR THE WATER YEAR 1962-63.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

General Summary

A goal of the research using the Stanford Streamflow Simulation Model performed at The Ohio State University was to create a streamflow simulation model applicable to both large and relatively small watersheds in the Midwest.

To accomplish this it was decided to utilize,as much as possible,concepts and programs from the Stanford Streamflow Simulation Model of Crawford and Linsley (1966) which was gaining much recognition as a good model for simulating streamflow in large basins. At the time, Dr. L. D. James was also utilizing the concepts of the Stanford Model in developing his Kentucky Version. It was this initial Version of the Kentucky Model that researchers at The Ohio State University began to work with. As a first step the model was studied in depth, an expose on its operation was written and the computer program was flow-charted. Much of the explanatory portion of this report reflects this work.

To gain insight into the behavior of the many input parameters a sensitivity study was performed by applying the model to the North Appalachian Experimental Watershed at Coshocton, Ohio. Here the opportunity arose to attempt to model small (down to 122 acres) rural watersheds. This application study uncovered deficiencies in the model if it is to be used for modeling small Midwestern watersheds. Systematically these deficiencies were reduced through modifications, extensive in some cases, to produce what is felt to be a reliable and useable streamflow simulation model, particularly for the smaller Midwestern watersheds.

The major modifications were presented in detail in this report and are separately summarized below. Also,as the modifications were tested and evaluated,other problems, though not too serious, were uncovered. These too are presented below to enlighten the reader and to suggest possible topics for additional research to further improve the model.

It is important to stress that a user of the model recognizes its abilities and drawbacks. A greater understanding and appreciation for the model will be realized if the input parameters are viewed in relation to the equations in which they are involved, and not as mere numbers that permit a computer program to return undeniable results.

Multiple Recession Constants Program

To expedite improvement of the interflow and groundwater flow recessions, a separate program to determine hydrograph recession constants was written. This program was designed to solve for multiple recession constants, which are the result of continuous relatively impervious stratum occurring in stratified areas of the North Appalachian Plateau. The program is based on Barnes' technique of hydrograph analysis and on the least squares method of curve fitting. After the appropriate recession constants had been determined, a mechanism for introducing them into the model was developed. This modification produce an improvement in the interflow and baseflow simulation. While recession curves were still not exactly simulated, because of neglecting the effect of intensity and duration of precipitation, they are at present much closer to the recorded flow and further modification will produce little improvement in yield or daily correlation.

The variable recession constants are tied to the quantity and intensity of precipitation but the model does not take this into account. However, groundwater is reasonably well simulated now and tying it to precipitation would probably do little to improve yield or the daily correlation.

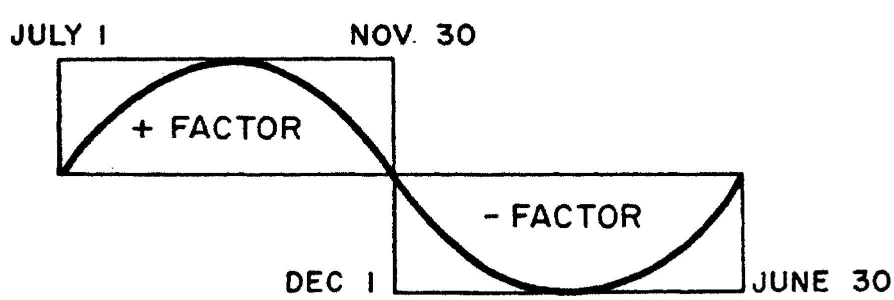
Swamp and Soil Crack Storage Consideration

The fall season simulation problem was greatly aided by diverting a portion of the runoff to upper zone storage in the form of swamp and marsh storage and soil crack storage.

Modification of the groundwater flow parameters CB, CY, and LZSN, increased the proportion of interflow and groundwater flow while maintaining approximately the same level of yield as before.

As a result of the above changes, a definite improvement was noted. Yield for the water year, daily correlation, interflow and groundwater flow were all generally improved.

The introduction of the variable FACTOR was made in step form (i. e., it either exists or does not). This does not seem too realistic. Instead, perhaps a



parabolic relationship would be appropriate as indicated in the sketch. Also, FACTOR has a drawback in that it greatly reduces yield for high intensity, short duration summer storms. Since these storms produce primarily surface runoff, FACTOR might be reduced by an appropriate test.

If further attempts to improve groundwater simulation are undertaken, consultation with an agronomist, familiar with the region of study, might well prove valuable.

Time Increment Changes for Small Watershed Studies

To make the model applicable to small watersheds, the previously fixed fifteen-minute routing interval was modified, as reported herein, to consider time increments down to 1 minute. To expedite this study, an option to plot the detailed storm by hydrograph and hyetograph was also incorporated into the model. These smaller routing periods produced better simulation on the smaller watersheds. A five-minute routing interval is suggested for future research on watersheds of similar size since the one and three-minute increment simulation results do not justify the excessive computer time required.

As the model now exists, precipitation inputs are on 15 minute intervals. To further improve simulation in small watersheds efforts should be directed to a modification for reading in precipitation at an interval corresponding to the chosen routing increment. Possibly an external program could be designed to automatically calculate the selected interval rainfall rate from gage data and simultaneously load this revised data.

Snowmelt Program for Handling Winter Simulation

This report also presents a workable snowmelt subroutine in the O. S. U. version of the Stanford Watershed Model for application on rural Midwestern watersheds.

To aid in accelerating the analysis, an option was programmed into the model which would print out the important hourly snowmelt variables. This option could prove to be a very useful tool in studying the simulated results and comparing them to the available field data. The data which should be taken in the future, ranked in order of importance, are: hourly temperatures, volume of snow in equivalent inches of water, absorbed radiation per hour, average hourly wind movement, hourly dewpoint temperatures, volume of snow in equivalent inches of water, absorbed radiation per hour, average hourly wind movement, hourly dewpoint temperatures, and the liquid water content of the snowpack. To use the option successfully, meterological stations should add the pertinent records found above, which they do not record, to their list of field data.

Results of this study show that the snowmelt subroutine is quite workable for the data available at Coshocton, Ohio; and will improve the correlation between synthesized and recorded streamflows. After several trial and error computer runs were made to determine the best values for the cold content build-up rate and the initial thermal quality of the snow, a statistical analysis was computed for the Little Mill Creek watersheds. The results showed that both the timing and the quantity of runoff during the snow season had been greatly improved. A few mismatched hydrograph peaks were the result of the unavailability of more extensive data.

There are certain aspects of the subroutine which are rather questionable due to some of the assumptions and approximations used. The lack of field data, needed to substantiate the use of these approximations, could quite conceivably be collected in the near future. Below are some recommendations in data collection which could be very helpful in increasing the models simulation accuracy and further eliminate the possibility of making inaccurate assumptions:

1. The use of a continuous temperature recorder would be a valuable asset for determining the form of precipitation. Presently the hourly temperatures are calculated from daily maximum and minimum temperature data. However, the calculation is based upon a predetermined average time of their occurrence. So, not only could the maximum and minimum temperatures be assumed to occur at the wrong time of the day but also the temperatures of every other hour could be incorrect too.

   The continuous recorder would allow the temperature to be an hourly input along with the precipitation. This would be beneficial because the accuracy in determining the form of the precipitation would be improved and the amount of melt, which is largely controlled by temperature, would be simulated better.

2. Eventually, when more accuracy is needed for smaller watersheds, it will be necessary to input precipitation on a smaller time basis. Often records only show the total amount of precipitation at the end of the day. This could cause mis-matched peaks when the rain or snow is added to the model on the wrong hour of the day. Therefore, data for future studies may have to be processed more closely.

3. Radiation, which is the greatest factor in the ripening of the snowpack in Ohio, should definitely be recorded more conscientiously. It is not only important to know the amount of solar radiation per hour but also the portion of the radiation absorbed by the snow. A simple average daily albedo of the snow surface would be very helpful in simulating the amount of ripening that was produced by the absorbed heat from radiation.
4. Cold winters allow the groundwater to freeze and prevent the infiltration of precipitation into the ground. Therefore, most runoff from rain or melting snow will enter the streams without seeping into the soil. A daily record of whether the soil moisture is frozen or unfrozen would be most helpful in determining the amount of infiltration on a given day.

The main purpose of this aspect of the research was to provide the O. S. U. version of the Stanford Watershed Model IV with a snowmelt subroutine so that the model would better simulate winter runoff. This subroutine, evolving from the analysis of the available data at Coshocton, Ohio, does work for this Section of Ohio; however, it is important to stress that adjustments to the subroutine will be necessary when different areas of the Midwest are tested. The Model simulated the streamflows with fair accuracy but there are still some aspects which need significant refinement.

Future research with snowmelt may be oriented in the following directions:

1. Test the effectiveness of the subroutine on larger and smaller watersheds. Because the snowmelt subroutine determines snowmelt from average watershed conditions, there could be an upper size (area) limit to its effectiveness.

2. Program the model to read hourly temperatures and determine whether this information will help to better simulate the quantity and timing of the snowmelt.
3. Find a method for determining the extent of the frozen soil moisture conditions during the snow season. This will enable future research on groundwater recession flows to be done with greater ease.

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The Ohio State University Version of the Stanford Streamflow Simulation Model

PART II —
THE COMPUTER PROGRAM
AUGUST 1972

By
Vincent T. Ricca
Associate Professor
of Civil Engineering

**Office of
Water Resources Research
United States Department
of the Interior**

PROJECTS
B-005-OHIO
B-019-OHIO

**State of Ohio
Water Resources Center
Ohio State University**

THE OHIO STATE UNIVERSITY VERSION

of the

STANFORD STREAMFLOW SIMULATION MODEL

PART II - THE COMPUTER PROGRAM

Principal Investigator

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OFFICE OF WATER RESOURCES RESEARCH
U. S. Department of the Interior
Matching Grants B-005-OHIO, B-019-OHIO

July, 1972

THE OHIO STATE UNIVERSITY VERSION

of the

STANFORD STREAMFLOW SIMULATION MODEL

PART II - THE COMPUTER PROGRAM

ABSTRACT

The technical aspects of and the evolution of the Ohio State University Version of the Stanford Streamflow Simulation Model have been presented in a separate report - Part I.

Included herein, Part II, is the computer program for the model. To facilitate understanding the program structure, an overall flow diagram was drawn. Next, a dictionary listing of the program variables is given. Finally, a photocopy of the actual operating computer program printout is presented.

The application of the model is explained in a separate user's manual - Part III.

KEY WORDS

Descriptors: Simulation/Hydrologic Models/Computer Models/Streamflow Forecasting/Evapotranspiration/Hydrograph Analysis/Sedimentary Basins/Snowmelt/Time of Concentration/Small Watersheds/Agricultural Watersheds.

MATCHING GRANT

From: Office of Water Resources Research
U. S. Department of the Interior

To: Water Resources Center
The Ohio State University
Columbus, Ohio

HYDROLOGIC INVESTIGATIONS OF SMALL WATERSHEDS IN OHIO

Research With the Stanford Streamflow Simulation Model

1968-1972

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James Urban	Geologist	North Appalachian Exp. Watersheds
C. Richard Amerman	Engineer	North Appalachian Exp. Watersheds
Heggie N. Holtan	Director	USDA Hydrograph Laboratory

TABLE OF CONTENTS

PREFACE

The Ohio State University Version Of The Stanford Streamflow Simulation Model

For convenience of reading and handling, ease of extending or updating, and to suit the reader's particular interest, the publication of the material associated with this model will be reported in three separate volumes.

The volume titles and a brief account of their content are:

The Ohio State University Version of the Stanford Streamflow Simulation Model:

Part I -- Technical Aspects:

A detailed analytical and descriptive presentation of the basic model with discussions on the input and output options, modifications made, test applications, performance evaluation, and developmental topics for future research.

Part II -- The Computer Program:

Definition of program variables (386) and listing of the program statements (1881).

Part III -- User's Manual:

A working understanding of the model so that the potential user can use it efficiently and effectively as a tool in hydrologic investigation.

The technical details in Part I are needed if one wishes to study the basic operation of the model, in particular, if modifications or additions are planned. For the practicing engineer or researcher Parts II and III will suffice for successful running of the model.

The author would appreciate receiving comments concerning both applications of the model and modifications to its structure. Feedback of this nature would be useful for compiling data on the ranges of the initializing parameters with eventual inclusion in updated versions of the User's Manual.

ACKNOWLEDGEMENTS

The work performed in this report has been an interdisciplinary research effort involving faculty, students, and researchers from two branches of U.S. Department of Agriculture.

The report was compiled from six Master of Science theses (Balk, 1968, Briggs, 1969; Owen, 1970; Mease, 1970; Valentine, 1970; and Warns, 1971) from the Department of Civil Engineering, The Ohio State University.

This program is from a study which is a portion of a research project, Hydrologic Investigations of Small Watersheds in Ohio, administered by Dr. E. Paul Taiganides, Project Director, Department of Agricultural Engineering, The Ohio State University.

This research was aided by faculty colleagues: Drs. E. P. Taiganides, G.O. Schwab, and M. Y. Hamdy, Professors of Agricultural Engineering, and Dr. G. P. Hanna who at the time served as Director of the Water Resources Center, The Ohio State University. Their counsel and service on thesis reading committees was most helpful.

Many thanks are given to staff of the North Appalachian Experimental Watershed, Coshocton, Ohio, for their encouragement, cooperation, and inexhaustible efforts to supply test data. Mr. L. L. Harrold, Officer-in-Charge and Adjunct Professor of Agricultural Engineering was an inspiration to the students and member of their theses reading committee. Mr. J. L. McGuinness, Statistician, supplied much of the test data and assisted in the analysis and interpretation of the modeling results. Dr. W. Edwards, Soil Physicist, freely shared his knowledge of the test watershed soils. In the earlier stages, Mssrs. C. R. Amerman, Watershed Engineer, and J. B. Urban, Geologist, were instrumental in initiating the study.

Gratitude is expressed to Mr. H. N. Holton and his staff of the USDA Hydrograph Laboratory in Beltsville, Maryland. They assisted in determining some of the modeling parameters and supplied their reduced data on the test watersheds. Correspondence and meetings with this group provided much guidance during our endeavors.

Of course this entire project could not have been possible if it were not for the cooperation of Professors N. H. Crawford and R. K. Linsley, originators of the model and Dr. L. D. James, who unselfishly gave us his translated version of the model and provided guidance and encouragement throughout this project.

The consultation provided by the staff of The Ohio State University Numerical Computations Laboratory was indispensable during the computer program check-out.

Financial support for this project came from several sources: The Office of Water Resources Research; U. S. Department of the Interior; Matching Fund Grants B-005-OHIO and B-019-OHIO; The Ohio State University Departments of Civil Engineering and Agricultural Engineering, and Graduate Student Traineeships; Federal Water Pollution Control Administration, U. S. Department of the Interior.

Special thanks are due to the staff of The Ohio State University Water Resources Center, Dr. K. S. Shumate, Director, for their administrative assistance.

Finally, I would like to thank Mr. Roy Koch, Research Associate, for his assistance in producing this report.

Columbus, Ohio

Vincent T. Ricca
Principal Investigator

BLOCK DIAGRAM OF THE MODEL

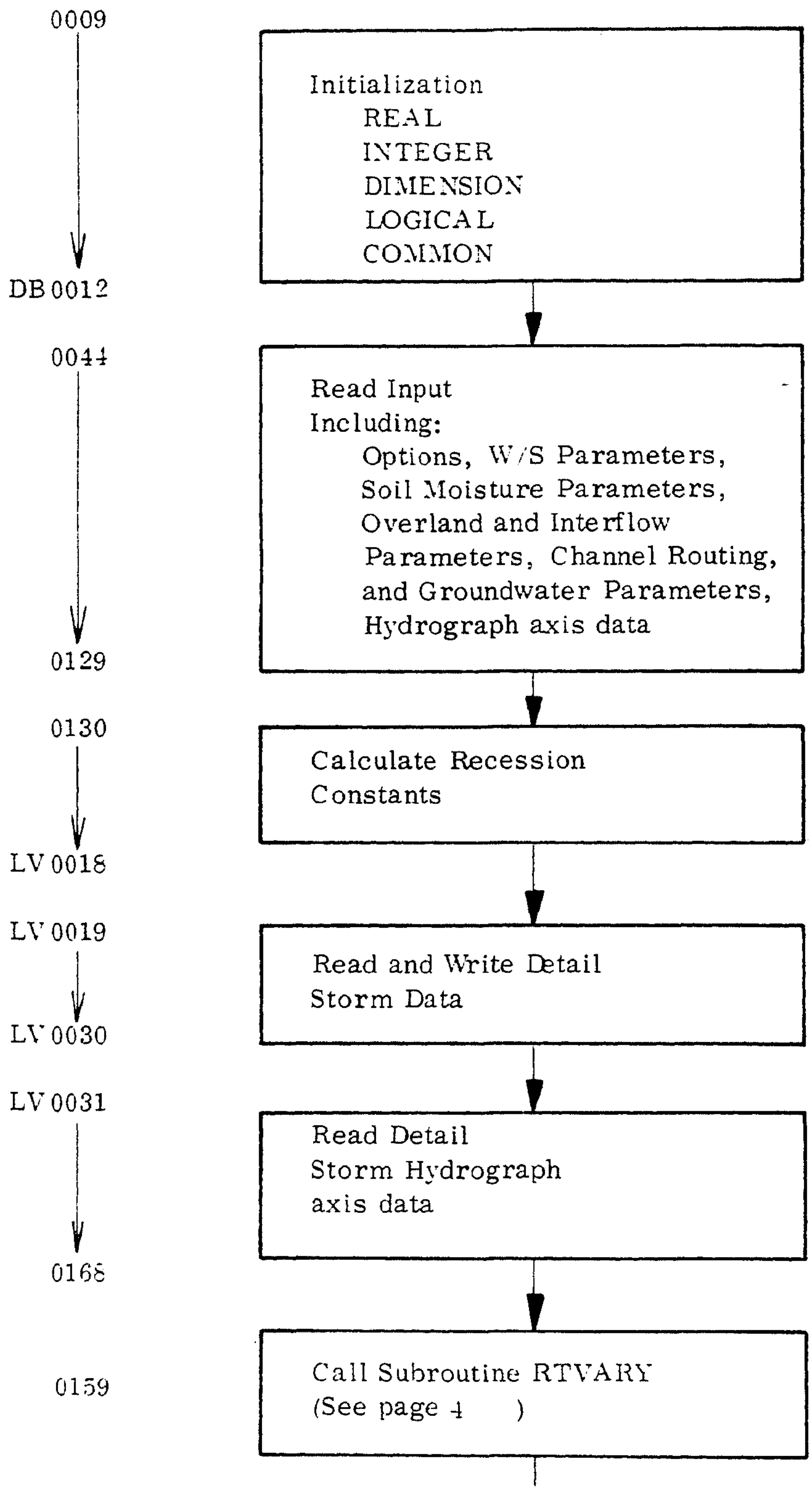
General Scheme

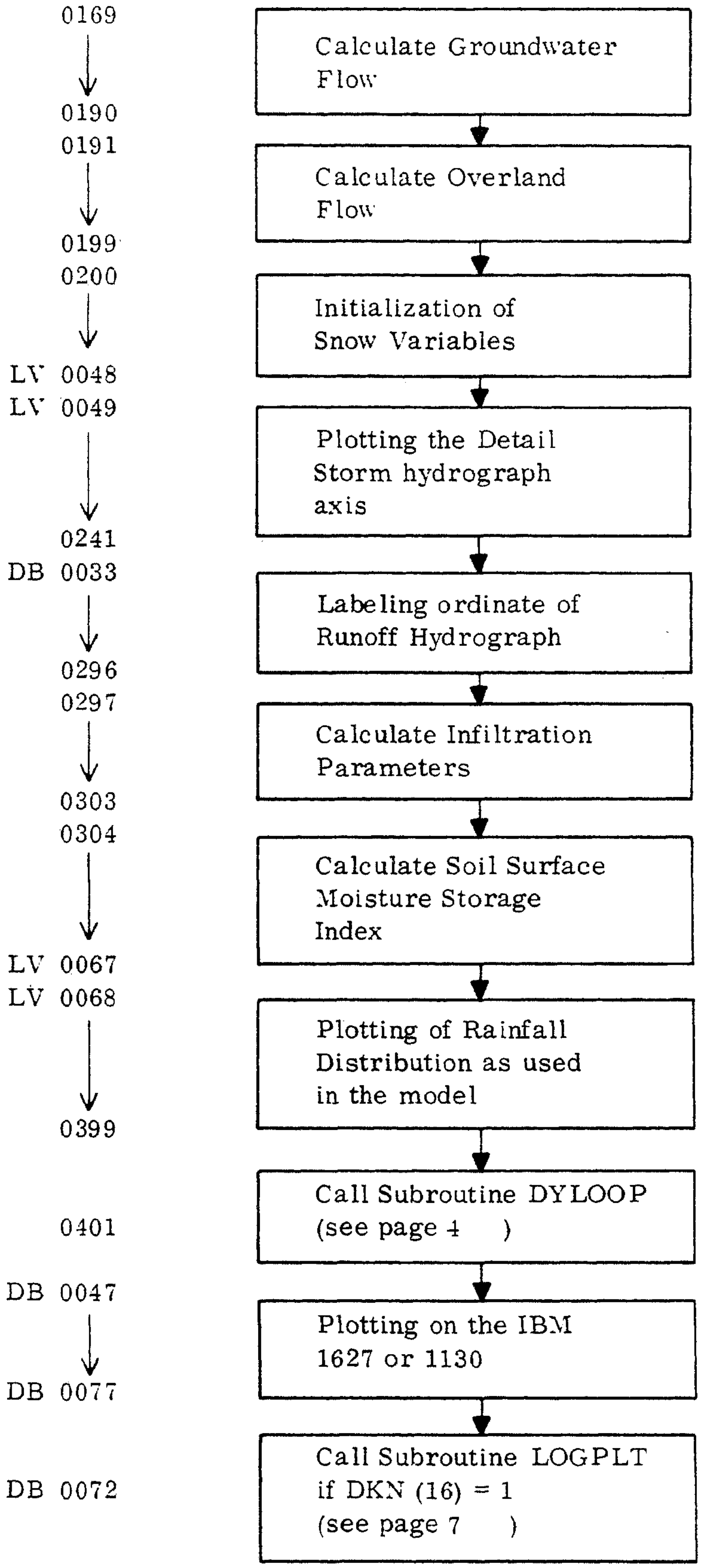
A general overview of the model's operation can be seen in the moisture accounting block diagram of Figure 1. A detailed expose on the model's construction with the supporting underlying hydrologic concepts is given in Part I - Technical Aspects of the Three-Part Report.

The following pages will present Figure 2, an overall logic flow diagram for the computer program. Detailed flow charts are on file at the Hydrology Research Laboratory at Ohio State University. These will not be presented herein since most modern computer facilities can automatically produce a flow chart from the program listing.

The blocks in Figure 2 represent as near as possible the subdivision sections that are delineated by asterisk line frames in the program listing. The actual statement numbers associated with each block are listed on its left side.

FIGURE 2. BLOCK DIAGRAM FOR THE OHIO STATE UNIVERSITY VERSION OF THE STANFORD STREAMFLOW SIMULATION MODEL




0169
Calculate Groundwater Flow
0190
0191
Calculate Overland Flow
0199
0200
Initialization of Snow Variables
LV 0048
LV 0049
Plotting the Detail Storm hydrograph axis
0241
DB 0033
Labeling ordinate of Runoff Hydrograph
0296
0297
Calculate Infiltration Parameters
0303
0304
Calculate Soil Surface Moisture Storage Index
LV 0067
LV 0068
Plotting of Rainfall Distribution as used in the model
0399
Call Subroutine DYLOOP (see page 4)
0401
DB 0047
Plotting on the IBM 1627 or 1130
DB 0077
Call Subroutine LOGPLT if DKN (16) = 1 (see page 7)
DB 0072

Call Subroutine LOGPL
if DKN (16) = 1
DB 0073 (see page 7)

DB 0074 Call Subroutine ARITHP
if DKN (17) = 1
(see page 7)

DB 0075 Call Subroutine ARITH
if DKN (17) = 1
(see page 7)

0429 Call Subroutine DAYOUT
(see page 7)

0437 → 0572 Write results

0574 → 0633

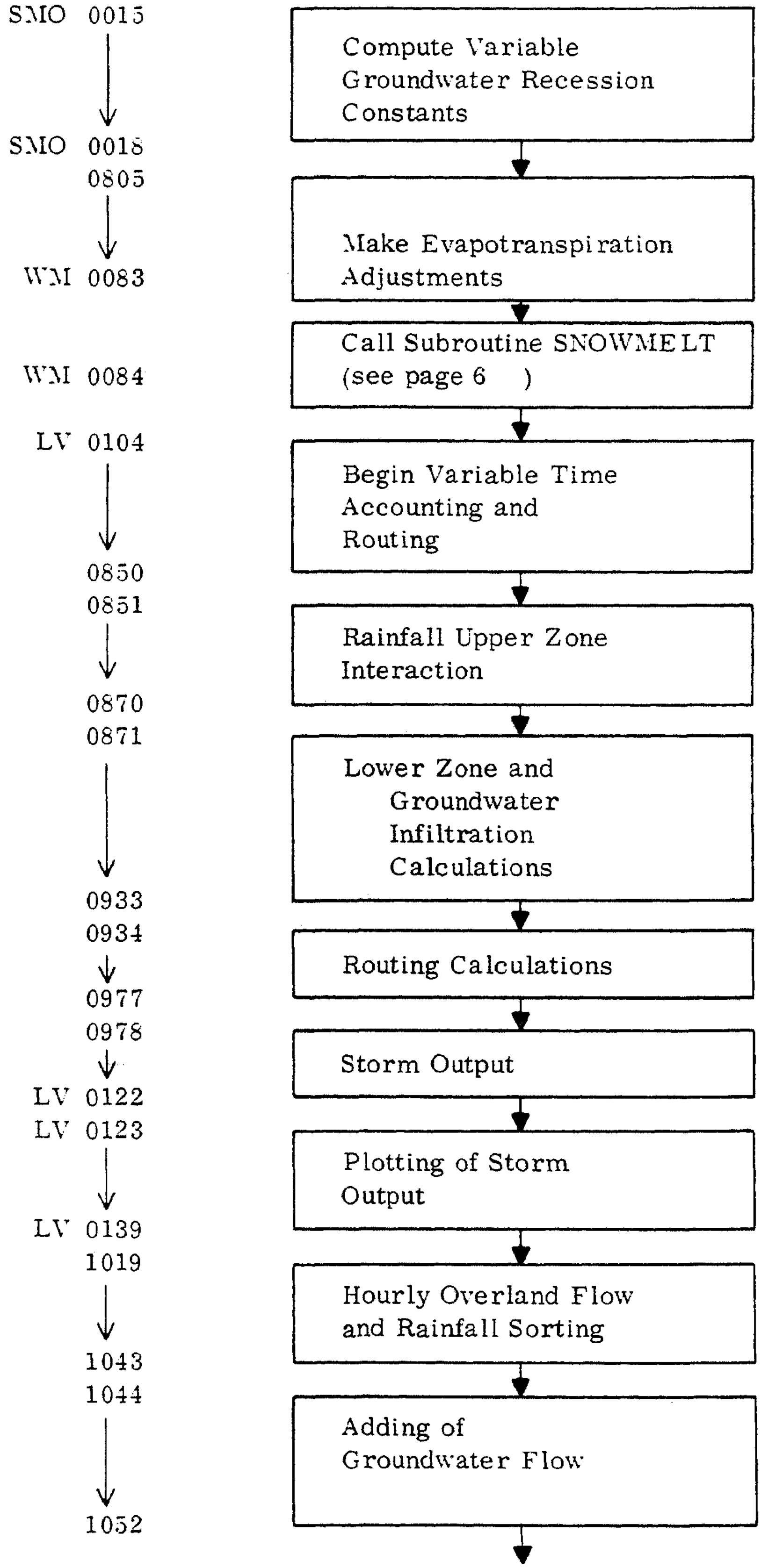
Subroutine RTVARY
Dummy Subroutine in the OSU Version. Used in the Kentucky Version to vary streamflow routing time according to streamflow magnitude

Subroutine DYLOOP
Performs most of the hydrologic computations

0701 → 0794

Initialization
REAL
INTEGER
DIMENSION
LOGICAL
COMMON

0799 → 0804 Compute Lake Evaporation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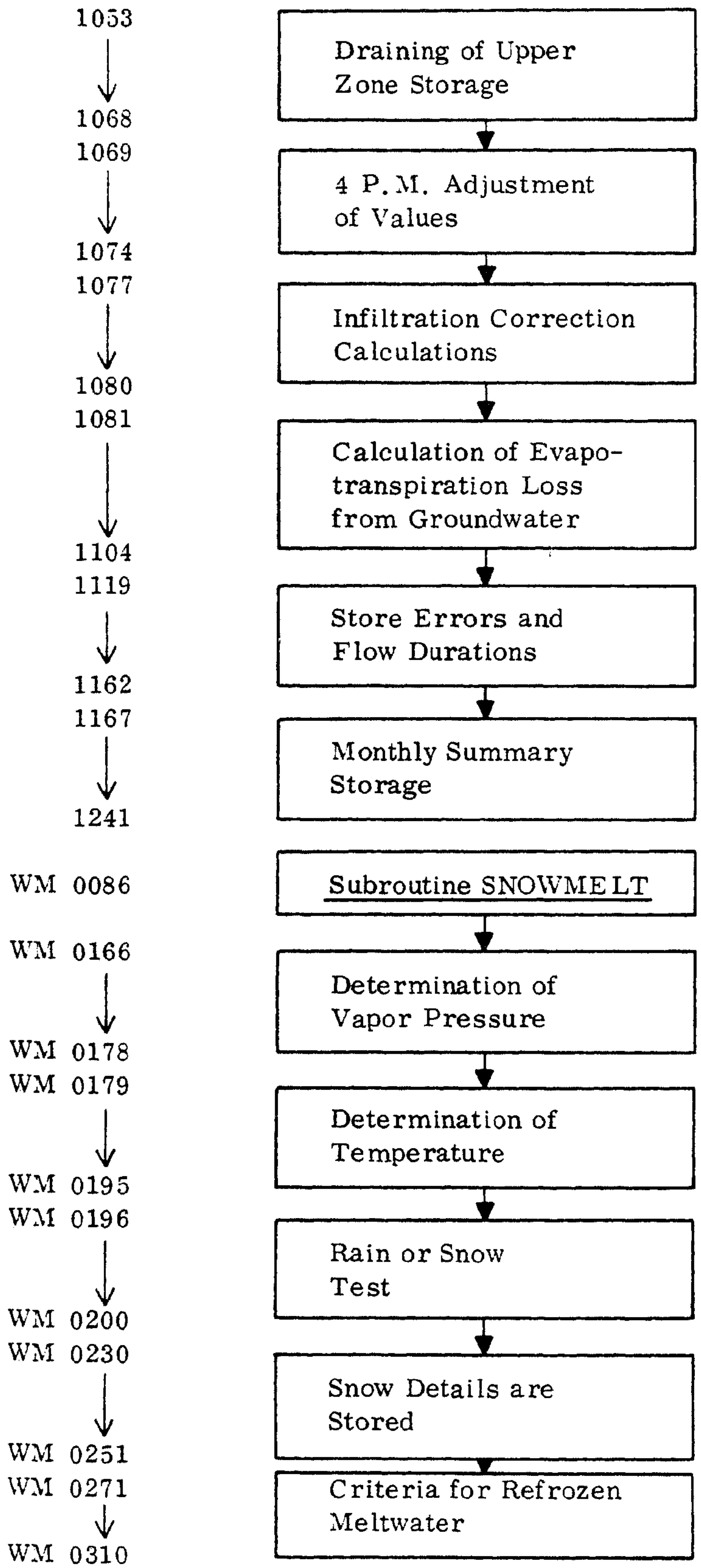
Lower Zone and Groundwater Infiltration Calculations
Routing Calculations
Storm Output
Plotting of Storm Output
Hourly Overland Flow and Rainfall Sorting
Adding of Groundwater Flow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0631 ↓ 0693	Subroutine DAYOUT Set-up data for output for one particular day
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0695 ↓ 0699	Subroutine Read Dummy Subroutine in the OSU Version to replace 360 Subroutine for a compilation check
DB 0116 ↓ DB 0138	Subroutine LOGPLT Plots Recorded Flows on a 5 cycle log scale from 0.01 to 1000.0 cfs
DB 0139 ↓ DB 0162	Subroutine LOGPL Plots Synthesized Flow in cfs with a dashed curve same scale as LOGPLT
DB 0145	Call Subroutine DASHC
DB 0163 ↓ DB 0185	Subroutine ARITHP Plots Recorded Flows on an arithmetic scale of the user's choice in cfs
DB 0186 ↓ DB 0209	Subroutine ARITH Plots Synthesized Flow in cfs with a dashed arithmetic curve of the same scale as ARITHP

DB 0192	Call Subroutine DASHC
DB 0210 ↓ DB 0275	Subroutine DASHC Used in LOGPL and ARITH to plot dashed hydrograph

DICTIONARY OF THE PROGRAM VARIABLES

The following listing are the names of the variables as used in the program. Along with the definition of the variable is information as to its Type (F, floating point: I, Integer), Dimension, and Units. All Input parameters are so indicated by an asterisk.

DICTIONARY OF PROGRAM VARIABLES

C.S.U. Version of the
Stanford Watershed Model

Version of May 1972

Variable	Type	Dimension	Units	Definition
A*	F	1	———	Impervious fraction of watershed surface
ACDIF	F	1	cfs	Difference between a recorded daily streamflow and the mean recorded daily streamflow
AET	F	1	in	Approximate annual lake evaporation
AETR	F	1	in	Synthesized daily evaporation from soil
AHOUR	F	1	hr	Hour of the day
ALANG*	F	366	Langleys/day	Total solar radiation per day
ALNG	F	1	Langleys/hr.	Total absorbed radiation per hour
AREA*	F	1	mi^2	Subwatershed drainage area
AXISX*	F	1	in	Length of abscissa for plotting hydrographs
AXISY*	F	1	in	Length of ordinate for plotting hydrographs
B*	F	1	———	Empirical constant for condensation
BAL	F	1	in	Moisture not accounted for within program
BPRI*	F	1	———	Empirical constant for evaporation
BSFLW	F	1	in/TINC	Baseflow
C*	F	99	———	Time-area histogram (May be modified in program according to streamflow)
C2	F	1	———	Multiplier used in programmed adjustment of infiltration rate
C2A	F	12	———	End of month value of C2
C2L	F	1	———	Old value of C2 preserved to test for change
C3	F	1	———	Variable controlling entry of moisture into interflow

CAAS	F	1	———	Number of daily events within a given interval on the error table
CAS	F	22	———	Array of daily events within error table intervals
CB*	F	1	———	Infiltration index
CBASE	F	99	———	Time-area histogram as read from data
CC	F	99	———	Time-area histogram correction factors to avoid loss of water when histogram shifts with streamflow
CDM	F	1	in	Condensation melt
CFS	F	1	cfs	Flowrate equalling one inch/hour of discharge from watershed
CFSD	F	1	sfd	Volume represented by one inch over the watershed
CHCAP*	F	1	cfs	Index capacity of existing channel
CN*	I	1	———	1 = A.M. : 2 = P.M.
COE*	F	1	———	Empirical constant for convection
CORCO	F	1	———	Correlation coefficient between daily and recorded streamflows
CVM	F	1	in	Convection melt
CX*	F	1	———	Index for estimating soil surface moisture storage
CY*	F	1	———	Interflow index
D23	F	1	———	Number of 15-minute period, varies from 1 to 4
D4F	F	1	in/TINC	Current peak infiltration rate
DAY*	I	1	———	Day of month or year
DD13*	I	1	———	Number of days of storage-gage input rainfall
DD15*	I	1	———	Day of year for corresponding storage gage rainfall
DD23	I	1	———	Number of 15-minute period, varies from 1 to 4
DD24	I	1	———	Counter used in routing time-area histogram elements
DD25	I	1	———	Counter used in adding monthly totals
DD26	I	1	———	Month-of-year counter for daily flow output table

DD27	I	1	———	Day-of-month counter for daily flow output table
DD30	I	1	———	Counter for error table intervals
DD33	I	1	———	Counter for overland-flow sorting
DD34	I	1	———	Counter for hourly rainfall sorting
DD35	I	1	———	Counter for printing 20 peak rainfall and runoff events
DD38	I	1	———	Day-of-year counter for computing error table statistics
DD45	I	1	———	Word counter for alphanumeric output
DDCOM	I	1	———	Control used in combining subwatershed flows
DDELDR*	F	1	cfs/in	The number of cubic feet per second per inch of ordinate used in plotting the arithmetic hydrograph
DDL	I	1	———	Day of year
DDLM	I	1	———	Day of year of last day of previous month
DDX*	F	10, 20	———	Label of abscissa for individual storm plot
DDY*	F	10, 20	———	Label of ordinate for individual storm plot
DDYEAR	I	1	———	Control used in combining subwatershed flows
DDYR1*	I	1	———	Last two digits of first year in water-year
DDYR2*	I	1	———	Last two digits of second year in water-year
DDZ	I	1	———	Number of time-area-histogram elements still to be routed
DE	F	1	in	Equilibrium surface detention storage (pervious surfaces)
DEC	F	1	———	Overland flow time index (pervious surfaces)
DEEPL	F	1	———	Index controlling infiltration rate of soil surface moisture
DELDR*	F	1	cfs/in	The number of cubic feet per second per inch of ordinate used in plotting the logarithmic hydrograph

ELH	F	1	in/day	Watershed evaporation from exposed water surfaces
EMIN*	F	1	———	The minimum value of EN
EN	F	1	———	Factor varying infiltration by season
ENA	F	12	———	End of the month values of EN
EP	F	1	in	Lake evaporation during day being analyzed
EPX	F	1	in/ TINC	Current interception rate
EPXM*	F	1	in/hour	Maximum interception rate for a dry watershed
ERR	F	1	cfs	Difference between average daily and recorded synthesized flows
ETEMP	F	1	in	Preliminary estimate of lake evaporation during day being analyzed
ETL*	F	1	———	Fraction of the total watershed in stream surface
EVCR*	F	12	———	Monthly evaporation pan coefficients
F*	F	1	———	Fraction of the total watershed in forest
F1	F	1	in	Infiltration water reaching groundwater
F13	F	1	in	Total infiltration
F3	F	1	in	Infiltration water held in the soil
FA	I	1	———	Current month of the water year
FACT*	F	15	———	Fraction of incoming radiation not absorbed by snow as a function of albedo
FACTOR	F	1	in	Volume of water which goes into swamp storage and dry ground expressed as inches over the watershed
FDD30	F	1	———	DD30
FDPY	F	1	———	DPY
FF1	F	1	in	Water infiltrating from soil surface storage to groundwater
FF3	F	1	in	Water infiltrating from soil surface storage but remaining in soil
FLO*	F	366	cfs	Recorded average daily flow
FLOO	F	1	cfs	Flow interval boundary printed on error table

DELDR1*	F	1	in	The spacing between tic marks for the ordinate of the logarithmic hydrograph
DELDR2*	F	1	in	The spacing between tic marks for the ordinate of the arithmetic hydrograph
DELT	F	1	days/in	The number of days per inch of abscissa used in plotting the arithmetic and logarithmic hydrographs
DELT5	F	1	in	The spacing between tic marks for the abscissa of the arithmetic and logarithmic hydrographs
DEN	F	1	———	Snow density
DEPTH	F	1	in	Average depth of snow on ground
DGM*	F	1	in/day	Rate of snowmelt from ground heat
DKN*	I	19	———	Program control array
DL*	F	1	in	The dash length used in plotting the synthesized hydrographs
DPY	I	1	———	Number of days in the year
DR	F	366	cfs	Synthesized average daily flow
DRORG*	F	1	———	The numeric lable for the minimum value of the ordinate at the axis origin for the logarithmic hydrograph
DRRORG*	F	1	———	The numeric label for the minimum value of the ordinate at the axis origin for the arithmetic hydrograph
DX	F	1	in	Location factor for labelling the abscissa of the detail storm
DY	F	1	in	Location factor for labelling the ordinate for the storm plot
E*	F	366	in	Daily pan evaporation
EDF*	F	1	———	Index for estimating soil surface moisture storage
EF*	F	1	———	Evaporation-infiltration factor
ELDIF*	F	1	1000 ft	Elevation difference between base thermometer and mean elevation of drainage basin

FRAC	F	1	hr	The selected routing time increment (TIMC) expressed as a decimal
GM*	F	1	in	Conduction melt (ground)
GWF	F	1	in/hr	Baseflow
GWS*	F	1	in	Current value of groundwater slope index
GWSA	F	12	in	End of month values of GWS
HAAP	I	12	———	Day of calendar year of last day of previous month (over the calendar year)
HARP	I	12	———	Day of calendar year of last day of previous month (over the water year)
HARPDR	F	12	cfs	Synthesized average daily flow
HOUR	I	1	———	Current hour of the day
HRDEC	F	1	hr	Current time of day expressed as a decimal
HRM	F	1	min	Time of flood peak (24 hour clock)
HRM12	F	1	min	Afternoon time of flood peak (12 hour clock)
I	I	1	———	Counter (most often day of year)
I1	I	1	———	Day of the year loop control parameter
I2	I	1	———	Day of the year loop control parameter
ICNT	I	1	———	Number of days for which 15 minute storm details have been printed out so far
IDNS*	F	1	———	Density of new fallen snow
IFACTR	F	1	in/hr/°day	Basic snowmelt rate
II	I	1	———	Counter used in writing synthesized daily streamflows
IIOUT	I	1	———	Day of the year of first day of storm detail output requested
IJK	I	1	———	Hour of the day used in reading hourly rainfall data
IJK1	I	1	———	Hour of the day loop control parameter
IJK2	I	1	———	Hour of the day loop control parameter
IJK3	I	1	———	Day of the year
IND	I	1	———	Error table interval counter

INTF	F	1	in/hour	Current rate at which interflow is entering channel
INUM*	I	1	———	Number of days of storm detail output requested
IOUT*	I	1	———	Day of the year of current day of storm detail output being provided
IPACK*	F	1	in	Minimum snowpack water at which entire basis is covered with snow
IPJ	I	1	———	Day counter for reading daily evaporation data
IRC*	F	1	———	Daily interflow recession constant
IRC4	F	1	———	12-minute interflow recession constant
IRRR	I	1	———	Control variable for combining subwatershed flows
ISEP	F	1	in	An evaporation parameter used to very infiltration
ITABLE	I	1	———	Control variable for printing headings of storm detail table
ITI*	F	1	in	Index precipitation for changing snow albedo
IZ	I	1	———	Number of elements in read time-area histogram
IZL	I	1	———	Number of elements in low flow time-area histogram
J	I	1	———	Hour-of-the-day counter
J2	I	1	———	Hour counter for apportioning storage gage rainfall
JJ	I	1	———	Day counter used in writing synthesized d daily flows
JJJ	I	1	———	Element counter used in reading inpur arrays
JKL	I	1	———	Counter used to print-out daily soil moisture values
JKLM	I	1	———	Control variable for printing daily soil moisture table
JZ	I	1	———	Number of elements in current time-area histogram
K	F	366	———	Daily ratio of average rainfall over basin to average rainfall at recording gage

K1*	F	1	———	Long-term ratio of average rainfall over basin to average rainfall at recording gage
K24EL*	F	1	———	Groundwater evaporation parameter
K24L*	F	1	———	Parameter indicating groundwater flow leaving basin
K3*	F	1	———	Soil evaporation parameter
KINT*	F	1	———	Fraction of snow falling on forest intercepted by trees
KJI	I	1	———	Counter used in day loop control
KK24*	F	1	———	Daily base flow recession constant
KK4	F	1	———	Hourly base flow recession constant
KRN	F	1	———	Daily ratio of average rainfall over basin to average rainfall at recording gage
KS	F	1	———	Current value of streamflow routing parameter (through theoretical reservior)
KSC*	F	1	———	Streamflow routing parameter for low flows
KSF*	F	1	———	Streamflow routing parameter for flood flows
KV24*	F	1	———	Daily base flow recession adjustment factor
KV4	F	1	———	Hourly base flow recession adjustment factor
L*	F	1	ft	Mean overland flow path length
LIQS*	F	1	in.	Liquid-water-holding capacity of the snow
LIQW	F	1	in	Liquid water held in snowpack
LIRC4	F	1	———	Logarithm of IRC4
LKK4	F	1	———	Logarithm of KK4
LKV4	F	1	———	Logarithm of KV4
LNRAT	F	1	———	Current ratio of soil moisture storage to soil moisture storage index
LNRATM	F	1	———	Soil moisture index used in estimating current infiltration rate

LOS	F	1	in	Groundwater evaporation
LSF	F	1	in	Direct runoff and inter-flow routed to basin outlet
LZI	F	1	———	Intermediate soil moisture parameter for estimating infiltration
LZS*	F	1	in	Current soil moisture storage
LZS1	F	1	in	Beginning of year soil moisture storage
LZSA	F	12	in	End of the month soil moisture storage
LZSN*	F	1	in	Soil moisture storage index
MAXRAT*	F	1	in	Maximum rate of negative snowmelt accumulation
MEANAC	F	1	cfs	Synthesized average daily streamflow over the year
MEANSY	F	1	cfs	Recorded average daily streamflow over the year
MINH*	F	1	cfs	Flows are printed out each hour of the day if the flow in any hour exceeds this amount
MINTIA	F	12	in	Monthly snow moisture lost by interception
MINTLS	F	1	in	Current sum of snow moisture lost by interception during month
MM	I	1	———	Yearly counter used to increment the individual storm data
MO*	I	1	———	Month of the year
MODDAY	I	1	———	Day of the month
MSEVAP	F	12	in	Monthly snow evaporation
MSEVEP	F	1	in	Current sum of snow moisture lost by evaporation
MSN1	I	1	———	Statement number used in day loop control
MSN2	I	1	———	Statement number used in day loop control
MXRA	F	21	in	Twenty highest clockhour rainfall events during year
MXRO	F	21	in	Twenty highest clockhour runoff events during year
N	I	1	———	Word counter for alphanumeric output

NEGMEL	F	1	in	Negative snowmelt water currently in snowpack (indicates heat needed to raise pack to melting temperature)
NINC	I	1	———	The number of multiples of the routing time interval per hour
NN*	F	1	———	Manning's n for overland flow on soil surface
NNU*	F	1	———	Manning's n for overland flow on impervious surface
NX	I	1	———	Monthly counter for preparing or writing monthly summary output
NXDAY	I	100	———	Days with flood flows used for combining subwatersheds
NXIN	I	1	———	Day counter used in combining subwatershed flows
P1*	F	366, 24	in	Hourly recorded rainfall array
P1SUM	F	1	in	Variable for summing hourly rainfalls over day
P3	F	1	in	Residual rainfall after interception depletion
P4	F	1	in	Residual rainfall after soil surface moisture depletion
PA	F	1	———	Pervious fraction of watershed surface
PACK	F	1	in	Current snowpack water
PAR	F	1	———	Reciprocal of PA
PR	F	1	in/ TINC	Current rainfall rate
PR3	F	1	in/ TINC	Current interception rate
PRE	F	1	———	Fraction of incoming moisture retained in soil surface or soil storage
PREC*	F	366	in	Storage gage daily rainfall total
PRODIF	F	1	csf^2	Sum of the products for correlation
PX	F	1	in/hr	Average rainfall over basin
QQO*	A	10	———	Description of gage location
QQQ*	A	13	———	Title of computer run
QQY*	A	14	———	Title of ordinate for runoff hydrograph

QT	F	1	———	Thermal quality of the snowpack
QTI	F	1	———	The initial thermal quality of freshly fallen snow
R	F	99	in	Total direct runoff and interflow coming into stream by histogram interval
RADM	F	1	in.	Radiation melt
RATE	F	1	in/hr	The incremental cold content addition to the snowpack
RECE	F	1	in/hr	Current rate of soil surface moisture infiltration
RES	F	1	in	Carryover overland flow storage on pervious surfaces
RFC*	F	1	———	Exponent for equation V=K*Q**RFC used in subroutine "RTVARY"
RGX	F	1	in	Water entering interflow storage
RIGIQ	F	1	in/hr	Current streamflow routed downstream by time-area histogram
RM	F	1	in	Melt due to rain
RNA	F	1	in	Recorded annual precipitation
RNB	F	1	in	Annual rainfall plus snowmelt
ROFF	F	1	in	Current direct runoff and interflow coming into stream
ROS	F	1	in	Current overland flow reaching stream from pervious surfaces
RQOUT	F	1	in/ TINC	Direct runoff plus interflow for storm details table
RX	F	1	in	Current direct runoff
S	F	22	cfs	Standard error of synthesized flow by flow interval
SAB198	F	1	AF	Annual runoff
SABC	F	1	cfs	Variable used to sum synthesized daily flows (subwatershed)
SABCFS	F	1	in	Total synthesized annual runoff

SABD	F	1	cfs	Variable used to sum recorded daily flows
SABM	F	1	cfs	Variable used to sum recorded daily flows (total watershed)
SAET	F	1	in	Variable used to sum synthesized net evaporation
SAETA	F	12	in	Synthesized monthly net evaporation
SCASE	F	1	———	Total number of daily streamflows synthesized within current error table interval
SCF*	F	1	———	Multiplied by recorded snowfall to account for moisture missed by the gage
SDEN	F	1	———	Current snowpack density
SDIV*	F	366	cfs	Daily diversion data
SDR	F	366	cfs	Array used in combining synthesized daily flows among watersheds
SE*	F	366	in	Daily snow evaporation potential
SEP	F	1	in	An evaporation parameter used to vary infiltration
SERA	F	22	cfs	Sum of absolute errors of synthesized flows by interval
SERACS	F	1	cfs	Average absolute error of synthesized flows within flow interval
SERR	F	22	cfs	Algebraic sum of errors of synthesized flows by flow interval
SEVAP	F	1	in	Daily snow evaporation loss
SF	F	1	in	Current value of direct runoff and interflow routed to basin outlet
SFM	F	1	cfs	Synthesized peak streamflow for day
SFX	F	1	cfs	Current synthesized streamflow
SFXIN	F	1	in/ TINC	Current synthesized streamflow
SGRT*	I	1	———	Hour of the day at which storage gage rainfall is read

SGRTT	I	1	———	Last hour of the day before storage gage rainfall is read
SGW*	F	1	in	Groundwater moisture storage
SGW1	F	1	in	Beginning of year groundwater moisture storage
SGWA	F	12	in	End of month groundwater moisture storage
SGWEA	F	12	in	Synthesized base flow during month
SHFT	I	1	———	True if time-area histogram shifted during current hour
SHRD	F	1	in	Sum of current moisture entering surface runoff plus interflows
SINT	F	1	in	Variable used to sum synthesized daily interflows
SINTA	F	12	in	Synthesized interflow during month
SL*	F	1	in	The space length used in plotting the synthesized hydrographs
SMELT	F	1	in	Total amount of melt from the snowpack
SMINTL	F	1	in	Annual snow interception loss
SMSURS	F	1	in	Annual snow evaporation loss
SOILM	F	366	in	Daily soil moisture storage array
SPET	F	12	in	Potential evaporation during month
SPETA	F	12	in	Potential evaporation during month
SPR	F	1	in	Variable used to sum recorded average rainfall over basin
SPRA	F	12	in	Average rainfall recorded on basin during month
SPRM	F	1	in	Variable used to sum rain plus snowmelt
SPRMA	F	12	in	Total rain plus melt during month
SPX1	F	1	in	Annual snowfall moisture
SPX2	F	1	in	Annual snowfall moisture reaching ground
SQER	F	22	cfs	Sum of squares of errors of synthesized flows by flow interval

SRC	F	1	———	Fraction of overland flow moisture storage reaching channel
SRCC	F	1	———	Value of SRC in absence of snow
SRFSN	F	1	cfs	Variable used to sum recorded daily flows from November through March
SRGX	F	1	in	Current water in interflow storage
SROS	F	1	in	Clockhour runoff event for sorting in MXRO
SS*	F	1	———	Average ground slope within watershed
SSAET	F	1	in	Synthesized annyal net evaporation
SSEP	F	1	in	An evaporation parameter used to vary infiltration
SSERA	F	1	cfs	Grand total of absolute errors of synthesized flows
SSERAQ	F	1	cfs	Average absolute error of synthesized flows
SSERR	F	1	cfs	Grand algebraic total of errors of synthesized flows
SSERRQ	F	1	cfs	Average error of synthesized flows
SSF	F	1	in	Hourly total of direct runoff and interflow routed to basin outlet
SSGR	F	1	———	SGRTT
SSGWF	F	1	in	Variable used to sum synthesized daily base flows
SSINT	F	1	in	Total synthesized annual interflow
SSNCFS	F	1	in	Total recorded annual flow from November through March
SSPET	F	1	in	Annual lake evaporation
SSRT	F	1	———	Square root of SS
SSTER	F	1	cfs	Sum of the standard errors
ST *	I	1	———	Number assigned recording rain gage by Weather Bureau
SUMRAN	F	1	in	Rainfall total for estimating effect of rainfall on snow albedo

SUMSN	F	1	in	Snowfall total for estimating effect of snowfall on snow albedo
SUMTR	F	1	cfs	Variable used to sum hourly streamflows
SWA*	F	37	———	Incidence of incoming radiation by time of year
SYDIF	F	1	cfs	Difference between a synthesized daily streamflow and the mean synthesized streamflow
SYM*	A	12	———	Title of abscissa for runoff hydrograph
T1	F	1	°F	Average 4 a.m. temperature over watershed
T2	F	1	°F	Average 4 p.m. temperature over watershed
TAREA*	F	1	mi^2	Total watershed drainage area
TCONC*	I	1	min	The time for water originating in the most remote region to reach the measuring station
TDEW*	F	15	°F	5 degree temperature increments corresponding to known vapor pressures
TDPT	F	366	°F	Average daily dewpoint temperatures
TEMP	F	1	°F	Hourly calculated temperatures over the watershed
TIME	F	1	in	Daily increment of abscissa used in plotting the runoff hydrographs
TIMNDX	F	1	———	Snow albedo index
TINC*	I	1	min	The selected routing interval in minutes
TMAX*	F	366	°F	Maximum recorded temperature during day
TMIN*	F	366	°F	Minimum recorded temperature during day
TOND	F	12	cfs	Total recorded streamflow by end of month
TONDIF	F	1	cfs	Total recorded streamflow during month
TONE	F	12	cfs	Total (subwatershed) synthesized streamflow through end of month
TONM	F	12	cfs	TONE over total watershed
TOTFW	F	1	in/ TINC	Total flow
TQT	F	1	———	The hourly stored thermal quality of the snow
TR	F	24	cfs	Synthesized hourly streamflows

TRS	F	100, 24	cfs	Synthesized hourly streamflows saved for combining subwatersheds
TZN	F	1	in	Total synthesized annual baseflow
UDE	F	1	in	Equilibrium surface detention storage (impervious surfaces)
UDEC	F	1	———	Overland flow time index (impervious surfaces)
UPR	F	1	in	Current overland flow on impervious surfaces
URES	F	1	in	Carryover overland flow storage on impervious surfaces
UROS	F	1	in	Current overland flow reaching stream from impervious surfaces
USRC	F	1	———	SRC (impervious surfaces)
USRCC	F	1	———	SRCC (impervious surfaces)
UZI	F	1	———	Intermediate soil surface moisture storage parameter for estimating depletion
UZS*	F	1	in	Current soil surface moisture storage
UZS1	F	1	in	Beginning of year soil surface moisture storage
UZSA	F	12	in	End of the month soil surface moisture storage
UZSN	F	1	in	Soil surface moisture storage index
USXNA	F	12	in	End of the month value of UZSN
VAP*	F	15	mb	Vapor pressure increments corresponding to known temperatures
VAPRES	F	1	mb	Average vapor pressure over the watershed per hour
VOLUME*	F	1	ac-ft	Volume of water assigned to swamp storage and dry ground recharge
VW*	F	366	mpd	Average daily wind movement
VWIND	F	1	mph	Average hourly wind movement
WC*	F	1	———	Water content of snow at saturation
WSG*	F	1	———	Storage gage weighting factor

XAX*	F	10	in	The length of abscissa for the indinidual storm plot
XLEN	F	1	in	Hour of day converted to individual storm plot scale
XORG*	F	10	——	Numeric label for the minimum value of the abscissa at the axis origin for the individual storm plot
XSYM	F	1	in	Horizontal location factor for labeling the abscissa of the runoff hydrograph
XTIC*	F	10	in	The spacing between tic marks for the abscissa of the detail storm plot
XUNIT*	F	10	hr/in	The number of hours per inch of abscissa used in plotting the individual storm
XX	F	366, 24	in	Hour of day expressed as a decimal converted to the individual storm plot scale
YAX*	F	10	in	The length of ordinate for the detail storm plot
YEAR*	F	1	AF	Recorded annual streamflow
YLEN	F	1	in	Streamflow in cfs converted to storm plot scale
YORG*	F	10	——	The numeric label for the minimum value of the ordinate at the axis origin for detail plot
YR*	F	1	——	Last two digits of calendar year-used also in program control
YRDET*	I	1	——	The number of years of data for the selected storm analysis
YSYM	F	1	in	Vertical location factor for labeling the ordinate of the runoff hydrograph
YTIC*	F	10	in	The spacing between tic marks for the ordinate of the storm plot
YUNIT*	F	10	cfs/in	The number of cubic feet per second per inch of ordinate used in the selected storm plot
YY	F	366, 24	in	Recorded rainfall array for the selected routing interval converted to detail storm plot scale

Z*	I	1	———	Number of elements in current time-area histogram
ZACDIF	F	1	cfs^2	Variable used to sum ACDIF squared
ZCDM	F	366, 24	in	Hourly values of melt from condensation
ZCVM	F	366, 24	in	Hourly values of melt from convection
ZFLCAT	F	10	in	Number of elements in read time-area histogram
ZIP	I	1	———	Control used in combining subwatershed flows
ZLQW	F	366, 24	in	Hourly values of the liquid water content
ZSYDIF	F	1	cfs^2	Variable used to sum SYDIF squared
ZPCK	F	366, 24	in	Hourly values of the water equivalent of the snowpack
ZPX	F	366, 24	in	Hourly values of the snowmelt runoff
ZRADM	F	366, 24	in	Hourly values of the melt from radiation
ZRM	F	366, 24	in	Hourly values of the melt from rainfall
ZTIC*	F	10	in	The spacing between tic marks for the ordinate of the rainfall hyetograph plot
ZTMP	F	366, 24	°F	Average temperature on the watershed per hour
ZUNIT*	F	10	in/in	The number of ordinate used in the rainfall hyetograph
ZYSNOT	F	1	in	Stores the amount of precipitation that is simulated as snow

PROGRAM LISTING

The following is a program listing of the May 1972 Ohio State University Version of the Stanford Streamflow Simulation Model.

The overall logic flow diagram is presented earlier in this report. An outline of the program is given below:

Deck A	Main Program
Deck B	Subroutine Rtvary (Not in operation)
Deck C	Subroutine Test
Deck D	Subroutine Snomel (Not in operation, subroutine has been replaced by a dummy)
Deck E	Subroutine Dayout
Deck F	Subroutine Read (Not in operation, subroutine has been replaced by a dummy)
Deck G	Subroutine Dyloop

Card columns 77 through 80 contain identification numbers for reference.

Information regarding computer facilities required to process this program are given in the Part III - User's Manual report.

```
C     OHIO STATE UNIVERSITY WATERSHED MODEL -- VERSION OF  MAY, 1972        JWC001
C     INCORPORATES OHIO STATE UNIVERSITY VARIATIONS TO                      JWC002
C     GROUNDWATER, SNOWMELT, AND TIME OF CONCENTRATION                      JWC003
C     BASED ON KENTUCKY VERSION OF DECEMBER 7,1967                             0005
C     BASED ON ORIGINAL FORTRAN TRANSLATION OF STANFORD WATERSHED MODEL       0006
C     III AND CHANGES TO INCORPORATE CERTAIN FEATURES OF MODEL IV             0007
C     VERSION OF DECEMBER 7, 1967.  RUN ON O.S.U. I.B.M. 370/165 SYSTEM       0008



      REAL MANN,LBS,K,KV4,KS,KSC,KSF,K24EL,K24L,ITI,LKV4,MEANAC               0009
      REALINTF,LZI,LZSN,LNRAT,KV24,K3,K1,LSF,KRN,LIGW,KK24,KK4                0010
      REALLKK4,LZS,MEANDY,MSEVEP,IPACK,IRC4,IRC                               0011
      REALLIRC4,ISEP,LZSI,MINTLA,MINTLS,NN,NNU,L,LNRATM                       0012
      REALMAXRC,MAXA,LZSA,MSEVAP,MAXRAT,IFACTR,KINI,NEGMEL,IONS               0013
      REAL LIGS                                                             WM0076
      INTEGERDD22,DD45,DD25,DD27,DD30,DD32,DD36,DD37,DD35,DD40,DD26           0014
      INTEGER DD15,DD24,DD33,DD34,DKN,ZIP,DD23,DD13,YR,Z,FA                   0015
      INTEGER TCONC, TINC, YRDET                                            LV0001
      INTEGERDCN,DDCOM,DDL,DDLM,DDYEAR,DDYR1,DDYR2,DDZ                        0016
      INTEGER PY,DAY,HOUR,HARP,HAAP,SGRTT,SGRT,CCD,CCO,ST                     0017
      DIMENSION HAAP(12)                                                      0018
      DIMENSION HARP R(12),TOTDIF(12)                                         0019
       DIMENSION FACT(15),SWA(37)                                             0020
      DIMENSION DCY(14),SYM(12)                                             DB0007
      DIMENSION XAX(10),XTIC(10),YAX(10),YTIC(10),ZTIC(10),ZUNIT(10),       LV0002
     1ZZX(10,25),ZZY(10,25),XX(366,24),YY(366,24),IIOUI(10)                 LV0003
      DIMENSION ADDDIF(12)
      LOGICALSHFT                                                             0021
      COMMON A,AHOUR,AITR, ASFLW,CC(99),C(99),CAS(22),CY,C3,CX,C2,CB,CFS      0022
     1,CHCAP,CKSF,CLL,C2A(12),CE,D4F,DD2,DD23,DEPTH,DKN(20),DDYR2,DDYR1,    WM0317
     2DDLM,DDL,DD13, PY, EC, DD24,DD23,DAY,DIRRNF,DD33,DD34,DEEPL,DR(366),    0024
     3DEV,DVCR(12), (366),EP,ETEMP,ETL,EPX,EOF,EN,EMIN,ENTRUZ,ENTRLZ,         0025
     4ELF,EPX,,F4,F,F3,F2,FL(366),GWF,GWS,GWSA(12),HRM,HRM12,HARP(12),I       0026
     5N ,     ICNT,IZL,IPACK,I,I1,I2,INTF,     ISEP,J,J2,J2,KSF,K(366),K    LV0004
     6JI,KRE,K24L,KS,KSC,K24EL,K3,LZSA(12),LDS,LIGW,LKV4,LSF,LNRAT,LZS,L      0028
     7NRATM,LZSM,LZI,LIRC4,LKK4,MSN2,MSN1,MSEVEP,MXRC(21),MXRA(21),MINH,      0029
     8MEANDAY,MSEVAP(12),MINTLA(12),MINTLS,NXIN,NXDAY(100),NEGMEL,OVFLST,     0030
     9OUTFLW,PAP,PRE,PR,P2,P4,PX,PACK,P1SUM,PREC(366),P1(366,24),PA           0031
        COMMON DR (20)                                                        0032
      COMMON      RE(15),RUFF,ROUUT,R(99),RIGIG,RES,RCS,RGX,RX,RECE,SIN       0033
     1T,SATC,SATL,SASM,SGRTT,SGRT,SSGR,SPRM,SPR,SPRA(12),SPETA(12),SINTA      0034
     2(12) ,      SGWFA(12),SPRMA(12),SAETA(12),SAET,SPET,SSEP,     SFX,SS    0035
     3GWF,SUMIR,SFM,SE(366),SEVAP,SDEN,SRDS,SSF,SHRD,SRGX,SEP,SRC,SGW,SH      0036
     4FT,SF,SOR(366),SOIV(366),SOILM(366),SERR(22),SERA(22),SGER(22),S(2      0037
     52),SSWA(12),IMAX(366),IMIN(366),TOTFLW,TR(24),TRS(100,24),TIMNOX,T      0038
     6ONE(12),TONM(12),TONO(12),JSRC,UZSN,UZS,UZI,UROS,UPR,URES,UDE,UDEC      0039
     7,UZSNA(12),UZSA(12),WSC,ZIP,Z,YR ,FNA(12),SRFSN,ZYSNCT                  0040
      COMMON SCF,MINT,CT,C 2,B,SPRI,CTI,LIGS,TDEW(15),VAP(15),VW(366),TO    WM0074
     1PT(366),ALANO(366),MAXRAT,ZPCK(366,24),ZTMP(366,24),ZLQW(366,24),Z    WM0075
     1PX(366,24),ZRM(366,24),ZCUM(366,24),ZCVM(366,24),ZRADM(366,24)        WM0077
        COMMON C, DDDIF, OVLDST, EF, ERR, LZSN                                0041
      COMMON TCONC,TINC,NINC,YRDET,XUNIT(10),YUNIT(10),XORG(10),YORG(10)    LV0005
     1,IOUT(10),INUM(10),MM,FRAC                                            LVC006
       COMMON CBASE(99), IZ, RFC, CFSD                                        0042
      COMMON FACTOR,VOLUME,AREA                                            SM00005
      COMMON SADDM
      COMMON SADD(366),SADDF1(12)
      DATAHAAP/0,31,59,90,120,151,181,212,243,273,304,334/                    0043
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *     DB0008
C     SYM IS DATA FOR LABELLING THE ABSCISSA OF THE RUNOFF HYDROGRAPH       DB0009
      DATA SYM/3HOCT,3HNOV,3HDEC,3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,3HJ    DBC010
```

```
     1HL,3HAUG,3HSEP/
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
          HARP(1)= 304
          HARP(2)=334
          HARP(3)=365
          HARP(4)= 31
          HARP(5)=59
          HARP(6)=90
          HARP(7)=120
          HARP(8)=151
          HARP(9)= 181
          HARP(10)=212
          HARP(11)=243
          HARP(12)= 273
      DAYFLK=1
      M=0
22222 CONTINUE
10001 DO 201 I=1,100
      XDAY(I)=0
      DO 201 J=1,24
  201 TRS(I,J)=0.0
      DO 199 I=1,   99
  199 R(I)=0.0
      DO 203 I=1,366
      SDIV(I)=0.0
      SDR(I)=0.0
  203 DR(I)=0.0
      DO 9001 JJJ=1,20
      READ(5,6000) DKM(JJJ)
 9001 WRITE(6,6000)DKM(JJJ)
 6000 FORMAT(I2)
      IF(DKM(15).EQ.1)WRITE(6,6999)
 6999 FORMAT(41H ****************************************)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(DKM(16).EQ.0.AND.DKM(17).EQ.0) GOTO4500
C                     HYDROGRAPH  AXES  DATA
      READ(5,5332)  DRORG,DELDR,DELDR1,DRRORG,DDELDR,DELDR2,AXISX,AXISY
 5332 FORMAT(8F10.6)
      IF(DKM(15).EQ.1) WRITE(6,5332) DRORG,DELDR,DELDR1,DRRORG,DDELDR,DE
     1LDR2,AXISX,AXISY
      IF(DKM(15).EQ.1) WRITE(6,6999)
C          SYNTHESIZED HYDROGRAPH DASH LENGTH AND SPACE LENGTH
      READ(5,5322) DL,SL
 5322 FORMAT(2F10.3)
      IF(DKM(15).EQ.1) WRITE(6,5322) DL,SL
      IF(DKM(15).EQ.1) WRITE(6,6999)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      CALL PLOT(0.,.5*(29.-AXISY),-3)
      CALL PLCTRD(-5.,AXISX+10.,-5.,AXISY+1.,1)
 4500 DDCON=1
      TAREA=0.0
11111 CONTINUE
10002 YR=0
      IF(DDCON.LE.0.AND.DKM(K).NE.1) GO TO 1
      READ(5,6001)TCONC,TINC,Z
      IF(DKM(15).EQ.1) WRITE(6,6001) TCONC,TINC,Z
 6001 FORMAT(3I5)
      NINC=60/TINC
      FRAC=FLOAT(TINC)/60.
      IF(DKM(15).EQ.1)WRITE(6,6999)
      DO 9002 JJJ=1,Z
      READ(5,6002) C(JJJ)
```

```
9002 IF(DKN(15).EQ.1) WRITE(6,6002) C(JJJ)
6002 FORMAT(F10.3)
     IF(DKN(15).EQ.1)WRITE(6,6999)
  2  READ(5,6003)MINH
     IF(DKN(15).EQ.1) WRITE(6,6003) MINH
6003 FORMAT(F10.3)
     IF(DKN(15).EQ.1)WRITE(6,6999)
     READ(5,6004)K1,AREA,A,ETL,EMIN
     IF(DKN(15).EQ.1) WRITE(6,6004) K1,AREA,A,ETL,EMIN
6004 FORMAT(5F10.3)
     IF(DKN(15).EQ.1)WRITE(6,6999)
     READ(5,6005)EPXM,CX,EDF,LZSN,K3,K24L,K24EL,FF,CB,CY
     IF(DKN(15).EQ.1) WRITE(6,6005)EPXM,CX,EDF,LZSN,K3,K24L,K24EL,FF,CB
    1,CY
6005 FORMAT(10F8.3)
     IF(DKN(15).EQ.1)WRITE(6,6999)
     READ(5,6006)SS,L,NN,NNU,IRC
     IF(DKN(15).EQ.1) WRITE(6,6006)SS,L,NN,NNU,IRC
6006 FORMAT(4F10.3,F20.18)
     IF(DKN(15).EQ.1)WRITE(6,6999)
     READ(5,6007)KSC,KSF,CHCAP,REC,KV24,KK24
     IF(DKN(15).EQ.1) WRITE(6,6007)KSC,KSF,CHCAP,REC,KV24,KK24
6007 FORMAT(5F10.3,F20.18)
     IF(DKN(15).EQ.1)WRITE(6,6999)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                       RECESSION  CONSTANTS
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     KK4=KK24**(1.0/24.0)
     LKK4=-ALOG(KK4)
     KV4=KV24**(1.0/24.0)
     LKV4=-ALOG(KV4)
     IRC4=IRC**(1./(24.*60./FLOAT(TINC)))
     LIRC4=-ALOG(IRC4)
C        NO CARD NUMBER 14}
     IF(DKN(1).EQ.0) GOTO4000
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C    DETAIL  STORM  DATA
     READ(5,4005) YRDET
     WRITE(6,4005) YRDET
4005 FORMAT(I5)
     WRITE(6,6999)
     DO 4733 I=1,YRDET
     READ(5,6008) IOUT(I),INUM(I)
     WRITE(6,6008)IOUT(I),INUM(I)
6008 FORMAT(2I5)
     IIOUT(I)=IOUT(I)
     IF(DKN(20).EQ.0) GOTO4733
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C    DETAIL  STORM  HYDROGRAPH  AXES  DATA
     READ(5,4001) XORG(I),XAX(I),XTIC(I),XUNIT(I),YORG(I),YAX(I),YTIC(I
    1),YUNIT(I),ZTIC(I),ZUNIT(I)
     WRITE(6,4001)XORG(I),XAX(I),XTIC(I),XUNIT(I),YORG(I),YAX(I),YTIC(I
    1),YUNIT(I),ZTIC(I),ZUNIT(I)
4001 FORMAT(10F5.2)
     READ(5,4002) (DDX(I,J),J=1,8)
     WRITE(6,4002)(DDX(I,J),J=1,8)
4002 FORMAT(8(1X,A4))
     READ(5,4003) (DDY(I,J),J=1,22)
     WRITE(6,4003)(DDY(I,J),J=1,22)
4003 FORMAT(20A4/2A4)
4733 WRITE(6,6999)
     CALL PLOT(0.0,.5*(29.-YAX(1)),-3)
```

```
 4000 READ(5,6009)SGW,UZS,LZS,GWS
      IF(DKN(15).EQ.1) WRITE(6,6009)SGW,UZS,LZS,GWS
 6009 FORMAT(4F10.3)
      IF(DKN(15).EQ.1)WRITE(6,6999)
      READ(5,6101) VOLUME
      IF(DKN(15).EQ.1) WRITE(6,6101) VOLUME
 6101 FORMAT(F10.2)
      IF(DKN(15).EQ.1) WRITE(6,6999)
      IF (DKN(12) .NE. 1) GO TO 19903
      IZ=Z
      ZFLOAT = Z
      IZL=(10.0**RFC)*ZFLOAT+0.5
      JZ=99
      DO 19904 I = 1, IZ
19904 CBASE(I) = C(I)
      SFX = 1.0
      CALL RTVARY (C,CC,CBASE,CHCAP,IZ,IZL,JZ,RFC,SHFT,SFX)
19903 CONTINUE
    4 AET = 0.0
      C2 = 1.0
      PA=1.0-A-FTL
      PAR=1.0/PA
      EPX=FRAC*EPXM
      DDZ=0
      RX=0.0
      INTF=0.0
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                        GROUNDWATER  FLOW
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      GWF=SGW*LKK4*(1.0+LKV4*GWS)
      RODUT=0.0
      RES = 0.0
      URES = 0.0
      SRGX = 0.0
      LSF = 0.0
      ROFF = 0.0
      SINT=0.0
      SAET=0.0
      SPET=0.0
      MSEVEP=0.0
      MINTLS=0.0
      SUMSN=0.0
      SUMRAN=0.0
       KS = KSC
      CFSD = 26.8888*AREA
      CFS=24.0*CFSD
      SFX = GWF*CFS
      SSRT = SQRT(SS)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                        OVERLAND  FLOW
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      SRC = 1020.0*SSRT/(NN*L)
      USRC = 1020.0*SSRT/(UNN*L)
      DEC = 0.00982*((NN*L/SSRT)**0.6)
      UDEC = 0.00982*((UNN*L/SSRT)**0.6)
      SRCC=SRC
      USRCC=USRC
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                       SNOW VARIABLES INITIALIZED
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(DKN(7).EQ.0) GO TO 700
      TMEM(1)=30.
```

```
      TDEW(2)=35.
      TDEW(3)=40.
      TDEW(4)=45.
      TDEW(5)=50.
      TDEW(6)=55.
      TDEW(7)=60.
      TDEW(8)=65.
      TDEW(9)=70.
      TDEW(10)=75.
      TDEW(11)=80.
      TDEW(12)=85.
      TDEW(13)=90.
      TDEW(14)=95.
      TDEW(15)=100.
      VAP(1)=5.55
      VAP(2)=6.87
      VAP(3)=8.36
      VAP(4)=10.09
      VAP(5)=12.19
      VAP(6)=14.63
      VAP(7)=17.51
      VAP(8)=20.86
      VAP(9)=24.79
      VAP(10)=29.32
      VAP(11)=34.61
      VAP(12)=40.67
      VAP(13)=47.68
      VAP(14)=55.71
      VAP(15)=64.88
      IFACTR=0.
      WC=0.
      IPACK=0.
      SCF=1.0
      ELDIF=0.
      IDNS=0.
      F=.28
      KINT=.15
      MAXRAT=.0001
      ITI=0.
      T1=60.
      T2=60.
      TIMNDX=15.
      PACK=0.
      DEPTH=0.
      DEN=0.7
      SDEN=0.7
      SPX1=0.
      SPX2=0.
      NEGMEL=0.
      QT=0.0
      COE=.00177
      B=.0032
      BPRI=.0001
      LIWW=0.
      QTI=.90
      DO99930 MI=1,366
      TMAX(MI)=0.
      TMIN(MI)=0.
      VW(MI)=0.
      TDPT(MI)=0.
99930 ALANG(MI)=0.
  700 ZIP=0
```

```
      NXIN=0                                                            0211
   40 READ(5,5333,END=50)QQQ                                            OR0030
      GO TO 40                                                          OR0031
   50 IF(DKN(15).EQ.1) WRITE(6,5333) QQQ                                OR0032
 5333 FORMAT(20A4)                                                      0214
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0215
C  BEGIN NEW YEAR                                                       0216
    1 LZS1=LZS                                                          021
      UZS1=UZS                                                          0218
      SGW1=SGW                                                          0219
      ZYSNOT=0.                                                         WM0365
      MM=MM+1                                                           LV0047
      IF(DKN(20).EQ.0) GOTO4734                                         LV0048
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   LV0049
C     PLOTTING  THE  DETAIL  STORM  HYDROGRAPH  AXES                    LV0050
      CALL PLOT(XAX(MM)+9.5,0.0,-3)                                     LV0051
      CALL PLOTBD(-5.,XAX(MM)+10.,-1.,YAX(MM)+1.,1)                     LV0052
      CALL AXIS(0.,0.,4H    ,-4,XAX(MM),0.0,XORG(MM),XUNIT(MM),XTIC(MM)) LV0053
      DX=1.75                                                           LV0054
      DO4006 I=1,8                                                      LV0055
      CALL SYMBOL(DX,-.8,.28,DDX(MM,I),0.,4)                            LV0056
 4006 DX=DX+4.5                                                         LV0057
      CALL AXIS(0.,0.,4H    ,4,YAX(MM),90.,YORG(MM),YUNIT(MM),YTIC(MM)) LV0058
      DY=1.0                                                            LV0059
      DO 4007 I=1,22                                                    LV0060
      CALL SYMBOL(-1.0,DY,.28,DDY(MM,I),90.,4)                          LV0061
 4007 DY=DY+1.2                                                         LV0062
      CALL PLOT(XORG(MM),YAX(MM),3)                                     LV0063
 4734 DO 202 I=1,22                                                     LV0064
      CAS(I)=0.0                                                        0221
      S(I)=0.0                                                          0222
      SERR(I)=0.0                                                       0223
      SERA(I)=0.0                                                       0224
  202 SQER(I)=0.0                                                       0225
      KRN=K1                                                            0226
      DO 4444 I=1,21                                                    0227
      MXRO(I) = 0.0                                                     0228
      MXRA(I) = 0.0                                                     0229
 4444 CONTINUE                                                          0230
      P1SUM=0.0                                                         0231
      DDL=274                                                           0232
       IF(DDCOM.LE.0.AND.DKN(8).EQ.1) GO TO 5                           0233
      READ(5,6010)DDYR1,DDYR2,YEAR                                      0234
      IF(DKN(15).EQ.1) WRITE(6,6010)DDYR1,DDYR2,YEAR                    0235
 6010 FORMAT(2I3,F10.1)                                                 0236
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0237
      READ(5,5334)QQQ                                                   0238
      IF(DKN(15).EQ.1) WRITE(6,5334) QQQ                                0239
 5334 FORMAT(19X,15A4)                                                  0240
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0241
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   OR0033
C DDY IS ALPHANUMERIC DATA FOR LABELING THE ORDINATE OF THE RUNOFF      OR0034
C HYDROGRAPH--THIS SHOULD BE CHANGED FOR EACH WATER YEAR AND WATERSHED  OR0035
      READ(5,6090) DDY                                                  OR0036
 6090 FORMAT(1X,14A4)                                                   OR0037
      IF(DKN(15).EQ.1) WRITE(6,6090) DDY                                OR0038
      IF(DKN(15).EQ.1) WRITE(6,6999)                                    OR0039
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   OR0040
      DPY=365                                                           0242
      IF(MOD(DDYR2,4).EQ.0) DPY=366                                     0243
      IF(DKN(1).NE.1) GO TO 500                                         0244
      ICNT = 0                                                          0245
```

```
      IOUT(MM)=IIOUT(MM)
  500 HARP(5)=59
      IF(DPY.EQ.366) HARP(5)=366
      IF(DKN(3).EQ.0)GO TO 7
      DO 9011 JJJ=274,360,10
      READ(5,6011)E(JJJ)
 9011 IF(DKN(15).EQ.1) WRITE(6,6011) E(JJJ)
      IF(DKN(15).EQ.1)WRITE(6,6999)
      DO 9012 JJJ=1,273,10
      READ(5,6011) E(JJJ)
 9012 IF(DKN(15).EQ.1) WRITE(6,6011) E(JJJ)
      IF(DKN(15).EQ.1)WRITE(6,6999)
      DO 207 J=1,9
      DO 208 I=274,360,10
      IPJ= I+J
  208 E(IPJ)=E(I)
      DO 207 I=1,273,10
      IPJ= I+J
      IF(IPJ.GT.273) GO TO 207
      E(IPJ)=E(I)
  207 CONTINUE
      E(366)=E(59)
      E(365)=E(363)
      E(364)=E(363)
      GO TO 9907
    7 DO 9014 JJJ=274,365
      READ(5,6011) E(JJJ)
 9014 IF(DKN(15).EQ.1) WRITE(6,6011) E(JJJ)
 6011 FORMAT(F6.3)
      IF(DKN(15).EQ.1)WRITE(6,6999)
      DO 9015 JJJ=1,59
      READ(5,6011)E(JJJ)
 9015 IF(DKN(15).EQ.1) WRITE(6,6011) E(JJJ)
      IF(DKN(15).EQ.1)WRITE(6,6999)
      IF(DPY.LT.366)GOTO5555
       READ(5,6011) E(366)
      IF(DKN(15).EQ.1) WRITE(6,6011) E(366)
      IF(DKN(15).EQ.1)WRITE(6,6999)
 5555 DO9017JJJ=60,273
      READ(5,6011) E(JJJ)
 9017 IF(DKN(15).EQ.1) WRITE(6,6011) E(JJJ)
      IF(DKN(15).EQ.1)WRITE(6,6999)
 9907 DO 9013 JJJ=1,12
      READ(5,6012) EVCR(JJJ)
 9013 IF(DKN(15).EQ.1) WRITE(6,6012) EVCR(JJJ)
 6012 FORMAT(F10.3)
      IF(DKN(15).EQ.1)WRITE(6,6999)
      IF (AET.NE.0.0) GO TO 9018
      DO 9024 I=1,DPY
 9024 AET = AET + E(I)
      IF(EVCR(6).NE.1.0)AET=0.7*AET
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                       INFILTRATION   PARAMETERS
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      ISEP=24.0*AET/365.0
      SSEP=1.2*ISEP
      SEP=0.3*ISEP
      EN = 1.2**EF
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                              UZSN
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      UZSN=EDF*SEP+CX*EXP(-2.7*LZS/LZSN)
```

```
      IF(UZSN.LT.0.25) UZSN=0.25                                        0308
 9018 IF(DKN(9).NE.1) GO TO 9023                                        0309
      AET=0.0                                                         DR0041
      DO 8024 I=1,DPY                                                 DR0042
 8024 AET=AET+E(I)                                                    DR0043
      IF(FVCR(6).NE.1.0) AET=0.7*AET                                  DR0044
      ISEP=24.0*AET/365.0                                             DR0045
      DO 9019 JJJ=274,365                                               0310
      READ(5,6013) FLO(JJJ)                                             0311
 9019 IF(DKN(15).EQ.1) WRITE(6,6013) FLO(JJJ)                           0312
 6013 FORMAT(F10.3)                                                     0313
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0314
       DO 5100 JJJ=1,59                                                 0315
      READ(5,6013) FLO(JJJ)                                             0316
 5100 IF(DKN(15).EQ.1) WRITE(6,6013) FLO(JJJ)                           0317
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0318
      IF(DPY.LT.366)GOTO5556                                            0319
      READ(5,6013)FLO(366)                                              0320
      IF(DKN(15).EQ.1) WRITE(6,6013) FLO(366)                           0321
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0322
 5556 DO9022JJJ=60,273                                                  0323
      READ(5,6013) FLO(JJJ)                                             0324
 9022 IF(DKN(15).EQ.1) WRITE(6,6013) FLO(JJJ)                           0325
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0326
 9023 CONTINUE                                                          0327
      IF (DKN(11).NE.1) GO TO 9029                                      0328
      DO 9025 JJJ=274,365                                               0329
      READ(5,6014) SDIV(JJJ)                                            0330
 9025 IF(DKN(15).EQ.1) WRITE(6,6014) SDIV(JJJ)                          0331
 6014 FORMAT(F10.3)                                                     0332
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0333
      DO 9026 JJJ=1,59                                                  0334
      READ(5,6014) SDIV(JJJ)                                            0335
 9026 IF(DKN(15).EQ.1) WRITE(6,6014) SDIV(JJJ)                          0336
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0337
      IF(DPY.LT.366)GOTO5557                                            0338
      READ(5,6014)SDIV(366)                                             0339
      IF(DKN(15).EQ.1) WRITE(6,6014) SDIV(366)                          0340
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0341
 5557 DO9028JJJ=60,273                                                  0342
      READ(5,6014) SDIV(JJJ)                                            0343
 9028 IF(DKN(15).EQ.1) WRITE(6,6014) SDIV(JJJ)                          0344
      IF(DKN(15).EQ.1)WRITE(6,6999)                                     0345
 9029 CONTINUE                                                          0346
    5 IF(DKN(7).EQ.0) GO TO 9036                                        0347
      DO 9032 JJJ=305,365                                             WM0031
      READ(5,97620)(TDPT(JJJ),VW(JJJ),ALANG(JJJ),TMAX(JJJ),TMIN(JJJ)) WM0032
97620 FORMAT(F7.0,F8.0,F7.0,2F5.0)                                    WM0033
 9032 IF(DKN(15).EQ.1) WRITE(6,97620) TDPT(JJJ),VW(JJJ),ALANG(JJJ),TMAX( WM0091
     1JJJ),TMIN(JJJ)                                                  WM0092
      IF(DKN(15).EQ.1) WRITE(6,6999)                                  WM0093
      DO 9033 JJJ=1,59                                                WM0034
      READ(5,97620)(TDPT(JJJ),VW(JJJ),ALANG(JJJ),TMAX(JJJ),TMIN(JJJ)) WM0035
 9033 IF(DKN(15).EQ.1) WRITE(6,97620) TDPT(JJJ),VW(JJJ),ALANG(JJJ),TMAX( WM0094
     1JJJ),TMIN(JJJ)                                                  WM0095
      IF(DKN(15).EQ.1) WRITE(6,6999)                                  WM0096
      IF(DPY.LT.366)GO TO 5558                                        WM0036
      READ(5,97620)(TDPT(366),VW(366),ALANG(366),TMAX(366),TMIN(366)) WM0037
      IF(DKN(15).EQ.1) WRITE(6,97620) TDPT(366),VW(366),ALANG(366),TMAX( WM0098
     1366),TMIN(366)                                                  WM0099
      IF(DKN(15).EQ.1) WRITE(6,6999)                                  WM0100
 5558 DO 9035 JJJ=60,90                                               WM0038
```

```
      READ(5,97620)(TOPT(JJJ),VM(JJJ),ALANG(JJJ),TMAX(JJJ),TMIN(JJJ))
 9035 IF(DKN(15).EQ.1) WRITE(6,97620) TOPT(JJJ),VM(JJJ),ALANG(JJJ),TMAX(
     1JJJ),TMIN(JJJ)
      IF(DKN(15).EQ.1) WRITE(6,6999)
 9036 CONTINUE
      DO 210 I=1,366
      K(I)=K1
      PREC(I)=0.0
      DO 210 J=1,24
  210 P1(I,J)=0.0
      READ(5,6015)DD13
      IF(DKN(15).EQ.1) WRITE(6,6015)DD13
 6015 FORMAT(I3)
      IF(DKN(15).EQ.1)WRITE(6,6999)
      SGRT=0.0
      IF (DD13 .EQ. 0) GO TO 9
      READ(5,6016)WSG,SGRT
      IF(DKN(15).EQ.1) WRITE(6,6016)WSG,SGRT
 6016 FORMAT(F10.3,I4)
      IF(DKN(15).EQ.1)WRITE(6,6999)
      SGRTT=SGRT
      IF(SGRT.EQ.0) SGRTT=24
      SSGR=SGRTT
      DO 9037 JJJ=1,DD13
      READ(5,6017)DD15,PREC(DD15)
      IF(DKN(15).EQ.1) WRITE(6,6991) DD15,PREC(DD15)
 6991 FORMAT(I4,F10.3)
      IF(DKN(15).EQ.1)WRITE(6,6999)
 6017 FORMAT(I3,F10.3)
 9037 CONTINUE
 9    READ(5,6050)ST,YR,MO,DAY,CN
      IF(DKN(15).EQ.1) WRITE(6,6050) ST,YR,MO,DAY,CN
 6050 FORMAT(I5,3I2,I1)
      IF(DKN(15).EQ.1)WRITE(6,6999)
C       PUNCH NO NUMBERS AFTER CN ON YR .EQ. 98 CARD
      IF (YR.GE.98) GO TO4720
      IJK1=12*(CN-1)+1
      IJK2=12*(CN-1)+12
      IJK3=HAAP(MO)+DAY
       READ(5,6019)(P1(IJK3,IJK),IJK=IJK1,IJK2)
      IF(DKN(15).EQ.1) WRITE(6,6019) (P1(IJK3,IJK),IJK=IJK1,IJK2)
 6019 FORMAT(12F5.2)
      IF(DKN(15).EQ.1)WRITE(6,6999)
       IF(DPY.NE.366.OR.MO.NE.2.OR.DAY.NE.29) GO TO 9
      DO 211  I=IJK1,IJK2
      P1(366,I)=P1(60,I)
  211 P1(60,I)=0.0
      GO TO 9
 4720 IF(DKN(20).EQ.0) GOTO8
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     PLOTTING RAINFALL DISTRIBUTION AS USED IN THE MODEL
 4730 DO4701 I=1,24
      XX(IOUT(MM),I)=((FLOAT(ICNT)*24.+FLOAT(I))-XORG(MM))/XUNIT(MM)
      YY(IOUT(MM),I)=(YAX(MM)-P1(IOUT(MM),I)/ZUNIT(MM))-YORG(MM)
 4701 CONTINUE
      ICNT=ICNT+1
      IF((INUM(MM)+1).EQ.ICNT) GOTO4702
      IOUT(MM)=IOUT(MM)+1
      GOTO4730
 4702 ICNT=0
      IOUT(MM)=IIOUT(MM)
 4731 DO4703 I=1,23
```

```
      CALL PLOT(XX(IOUT(MM),I),YY(IOUT(MM),I),2)
      CALL PLOT(XX(IOUT(MM),I),YY(IOUT(MM),I+1),2)
 4703 CONTINUE
      CALL PLOT(XX(IOUT(MM),24),YY(IOUT(MM),24),2)
      CALL PLOT(XX(IOUT(MM),24),YY(IOUT(MM)+1,1),2)
      ICNT=ICNT+1
      IF(INUM(MM).EQ.ICNT) GOTO4705
      IOUT(MM)=IOUT(MM)+1
      GOTO4731
 4705 ICNT=0
      IOUT(MM)=IIOUT(MM)
      CALL PLOT(XORG(MM),YORG(MM),3)
    8 CONTINUE
C       BEGIN LOOP CONTROL
      CALLDYLOOP
      IF(YR.EQ.99)DDYEAR=DDYEAR+1
   55 WRITE(4,9901)(QQQ(N),N=1,20,1)
 9901 FORMAT(1H1,10X,20A4)
        WRITE(4,9902)(QQQ(DD45),DD45=1,15,1),DDYR1,DDYR2
 9902 FORMAT(1H/,15A4,3X,14H WATER YEAR 19,I2,1H-,I2,7X,
     123H O.S.U. WATERSHED MODEL)
C     ANNUAL SUMMARY
      SMINTL=0.0
      SMSURS=0.0
      SSINT=0.0
      SSPET=0.0
      SSAET=0.0
      RNB=0.0
      TZN=0.0
      RNA=0.0
      DO9101DD25=1,12,1
      RNA=RNA+SPRA(DD25)
      TZN=TZN+SGWFA(DD25)
      RNB=RNB+SPRMA(DD25)
      SSAET=SSAET+SAETA(DD25)
      SSPET=SSPET+SPETA(DD25)
      SSINT=SSINT+SINTA(DD25)
      SMSURS=SMSURS+MSEVAP(DD25)
 9101 SMINTL=SMINTL+MINTLA(DD25)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ** * * * *
C                        PLOTTING ON THE I.B.M. 1627
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DELT=365./AXISX
      DELT5=10./DELT
C     DKN(16) IS AN OPTION TO PLOT THE RUNOFF HYDROGRAPH
C     WITH RUNOFF LOGARITHMIC AND TIME ARITHMETIC
C     DKN(17) IS AN OPTION TO PLOT THE RUNOFF HYDROGRAPH
C     WITH RUNOFF ARITHMETIC AND TIME ARITHMETIC
      IF(DKN(16).EQ.0.AND.DKN(17).EQ.0) GO TO 9203
      IF(DKN(16).EQ.1) CALL AXIS(0.,0.,4H    ,-4,AXISX,0.,0.,DELT,DELT5)
      IF(DKN(17).EQ.1) CALL AXIS(0.,0.,4H    ,-4,AXISX,0.,0.,DELT,DELT5)
      XSYM=1.125
      DO 6066 I=1,12
      CALL SYMBOL(XSYM,-.8,.28,SYM(I),0.,3)
 6066 XSYM=XSYM+3.
      IF(DKN(16).EQ.1) CALL AXIS(0.,0.,3H    ,3,AXISY,90.,DRORG,DELDR,DEL
     1DR1)
      IF(DKN(17).EQ.1) CALL AXIS(0.,0.,3H    ,3,AXISY,90.,DRRORG,DDELDR,D
     1ELDR2)
      YSYM=3.5
      DO 6065 I=1,14
      CALL SYMBOL(-1.,YSYM,.28,DDY(I),90.,4)
```

```
6065 YSYM=YSYM+1.2                                                      080070
     DELT=AXISX/365.                                                    080071
     IF(DKN(16).EQ.1) CALL LOGPLT(FLO,DPY,DRORG,DELDR,DELT)             080072
     IF(DKN(16).EQ.1) CALL LOGPL(DR,DPY,DRORG,DELDR,DELT,DL,SL)         080073
     IF(DKN(17).EQ.1) CALL ARITHP(FLO,DPY,DRRORG,DDELDR,DELT)           080074
     IF(DKN(17).EQ.1)CALL ARITH(DR,DPY,DRRORG,DDELDR,DELT,DL,SL)        080075
     CALL PLOT(AXISX+9.5,0.,-3)                                         080076
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  080077
9203 IF(DKN(14).NE.1) GO TO 5004                                          0426
     WRITE(4,5018)                                                        0427
5018 FORMAT(1H/7X20HRECORDED STREAMFLOWS)                                 0428
     CALL DAYOUT(FLO,HARP,DPY)                                            0429
     WRITE(4,5019)                                                        0430
5019 FORMAT(1H///7X23HSYNTHESIZED STREAMFLOWS)                            0431
5004 CALL DAYOUT(DR,HARP,DPY)                                             0432
C    IF(DKN(8).EQ.1)GOTO10020                                             0433
10018 CONTINUE                                                            0434
     DO9112NX=1,11,1                                                      0435
9112 TONDIF(NX)=TONE(NX+1)-TONE(NX)                                       0436
     WRITE(4,9922)TONE(1),(TONDIF(NX),NX=1,11),SABC                       0437
9922 FORMAT(1X,14HSYN STREAMFLOW,12F7.0,2X,F9.0,2X,4HCFSD)              080078
     DO9113NX=1,11,1                                                      0439
9113 TONDIF(NX)=(TONE(NX+1)-TONE(NX))/CFSD                                0440
     TONDIF(12)=TONE(1)/CFSD                                              0441
     SABCFS=SABC/CFSD                                                     0442
     WRITE(4,9923)TONDIF(12),(TONDIF(NX1),NX1=1,11),SABCFS                0443
9923 FORMAT(1X,11HTOT SYN VOL,3X,12F7.3,4X,F7.2,2X,5HIN/YR)             080079
     WRITE(4,9924)(SINTA(NX),NX=1,12,1),SSINT                             0445
9924 FORMAT(1X,13HINTERFLOW VOL,1X,12F7.3,4X,F7.3,2X,5HIN/YR)           080080
     WRITE(4,9925)(SGWFA(NX),NX=1,12,1),TZN                               0447
9925 FORMAT(1X,13HBASE FLOW VOL,1X,12F7.3,4X,F7.3,2X,5HIN/YR)           080081
     IF(DKN(8).EQ.1.OR.DKN(9).EQ.0)GOTO10021                              0449
     SAB198=SABC*1.9835                                                   0450
     WRITE(4,9926)SAB198                                                  0451
9926 FORMAT(1X,42HANNUAL SYNTHESIZED STREAMFLOW IN ACRE FEET,58X,F9.0,2 080082
    1X,4HACFT)                                                          080083
     DO9114NX=1,11,1                                                      0453
9114 TONDIF(NX)=TOND(NX+1)-TOND(NX)                                       0454
     WRITE(4,9927)TOND(1),(TONDIF(NX),NX=1,11),SABD                       0455
9927 FORMAT(1X,14HREC STREAMFLOW,12F7.0,2X,F9.0,2X,4HCFSD)              080084
     SABCFS=SABD/CFSD                                                     0457
     WRITE(4,9928)SABCFS                                                  0458
9928 FORMAT(1X,34HRECORDED VOLUME IN INCHES PER YEAR,65X,F9.2,2X,5HIN/Y 080085
    1R)                                                                 080086
     SSNCFS=SRESM/CFSD                                                  080101
     WRITE(4,76509)SSNCFS                                               080102
76509 FORMAT(1X,55HRECORDED VOLUME IN INCHES PER YEAR FROM NOV. THRU MAR 080103
    1CH,45X,F9.2,2X,5HIN/YR)                                            080104
     IF(DKN(7).EQ.1) WRITE(4,80743)ZYSNOT                               080366
80743 FORMAT(1X,77HAMOUNT OF SYNTHESIZED SNOW FROM NOV. THRU MARCH IN EQ 080367
    1UIVALENT INCHES OF WATER,23X,F9.2,2X,6HINCHES)                     080368
     SAB198=SABD*1.9835                                                   0460
     WRITE(4,9929)YEAR,SAB198                                             0461
9929 FORMAT(1X,39HANNUAL RECORDED STREAMFLOW IN ACRE FEET,39X,1H(,F9.0, 080087
    12X,1H),9X,F9.0,2X,4HACFT)                                          080088
10021 CONTINUE                                                            0463
     WRITE(4,9930)(SPRA(NX),NX=1,12),RNA                                  0464
9930 FORMAT(1X,10HREC PRECIP,4X,12F7.2,3X,F8.2,2X,5HIN/YR)              080089
     WRITE(4,9934)(SAETA(NX),NX=1,12),SSAET                               0472
9934 FORMAT(1X,12HSYN E.T.-NET,2X,12F7.3,4X,F7.3,2X,5HIN/YR)            080090
     WRITE(4,9935)(SPETA(NX),NX=1,12),SSPET                               0474
9935 FORMAT(1X,14HPOTENTIAL E.T.,12F7.3,4X,F7.3,2X,5HIN/YR)             080091
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      WRITE(4,9936)(UZSA(NX),NX=1,12)
 9936 FORMAT(1X,12HSTORAGES-UZS,2X,12F7.3,13X,5HIN/YR)
      WRITE(4,9937)(LZSA(NX),NX=1,12)
 9937 FORMAT(10X,3HLZS,2X,12F7.3,13X,5HIN/YR)
      WRITE(4,9938)(SGWA(NX),NX=1,12)
 9938 FORMAT(10X,3HSGW,2X,12F7.3,13X,5HIN/YR)
      WRITE(4,9939)(UZSNA(NX),NX=1,12)
 9939 FORMAT(1X,12HINDICES-UZSN,2X,12F7.3)
      WRITE(4,9940)(GWSA(NX),NX=1,12)
 9940 FORMAT(10X,3HGWS,2X,12F7.3)
      IF(DKN(2).EQ.1)WRITE(4,9941)(C2A(NX),NX=1,12)
 9941 FORMAT(10X,2HC2,3X,12F7.3)
      WRITE(4,9942)(ENA(NX),NX=1,12)
 9942 FORMAT(10X,2HEN,3X,12F7.3)
      IF(DKN(7).NE.1)SCF=1.0
      BAL=(LZS+UZS-LZS1-UZS1)*PA+SGW-SGW1+(SABC/CFSD)+SSAET*PA-RMA
     1+SMSURS+SMINTL-((SCF-1.0)/SCF)*SPX1+SSPET*ETL
      WRITE(4,9944)BAL
 9944 FORMAT(1X,7HBALANCE,7X,F10.4,2X,6HINCHES)
      IF(DKN(19).EQ.0)GO TO 74113
      WRITE(4,30123)
30123 FORMAT(1H1,32X,'NOVEMBER'//,2X,'DAY',2X,'HOUR',2X,'TEMP.',3X,'RM',
     16X,'COM',5X,'CVM',4X,'RADM',4X,'LIOW',4X,'PACK',3X,'RUNOFF'/)
      DO 30124 I=305,334
      DO 30125 J=1,24
      KIJJ=I-304
      WRITE(4,30126)KIJJ,J,ZTMP(I,J),ZRM(I,J),ZCOM(I,J),ZCVM(I,J),ZRADM(
     1I,J),ZLOW(I,J),ZPCK(I,J),ZPX(I,J)
30126 FORMAT(2I5,F8.2,4F8.4,F7.3,F8.3,F7.3)
30125 CONTINUE
30124 CONTINUE
      WRITE(4,30127)
30127 FORMAT(///,32X,'DECEMBER'//,2X,'DAY',2X,'HOUR',2X,'TEMP.',3X,'RM',
     16X,'COM',5X,'CVM',4X,'RADM',4X,'LIOW',4X,'PACK',3X,'RUNOFF'/)
      DO 30128 I=335,365
      DO 30129 J=1,24
      KIJJ=I-334
      WRITE(4,30130)KIJJ,J,ZTMP(I,J),ZRM(I,J),ZCOM(I,J),ZCVM(I,J),ZRADM(
     1I,J),ZLOW(I,J),ZPCK(I,J),ZPX(I,J)
30130 FORMAT(2I5,F8.2,4F8.4,F7.3,F8.3,F7.3)
30129 CONTINUE
30128 CONTINUE
      WRITE(4,30131)
30131 FORMAT(///,32X,'JANUARY' //,2X,'DAY',2X,'HOUR',2X,'TEMP.',3X,'RM',
     16X,'COM',5X,'CVM',4X,'RADM',4X,'LIOW',4X,'PACK',3X,'RUNOFF'/)
      DO 30132 I=1,31
      DO 30133 J=1,24
      WRITE(4,30134)     I,J,ZTMP(I,J),ZRM(I,J),ZCOM(I,J),ZCVM(I,J),ZRADM(
     1I,J),ZLOW(I,J),ZPCK(I,J),ZPX(I,J)
30134 FORMAT(2I5,F8.2,4F8.4,F7.3,F8.3,F7.3)
30133 CONTINUE
30132 CONTINUE
      WRITE(4,30135)
30135 FORMAT(///,32X,'FEBRUARY'//,2X,'DAY',2X,'HOUR',2X,'TEMP.',3X,'RM',
     16X,'COM',5X,'CVM',4X,'RADM',4X,'LIOW',4X,'PACK',3X,'RUNOFF'/)
      DO 30136 I=32,59
      DO 30137 J=1,24
      KIJJ=I-31
      WRITE(4,30138)KIJJ,J,ZTMP(I,J),ZRM(I,J),ZCOM(I,J),ZCVM(I,J),ZRADM(
     1I,J),ZLOW(I,J),ZPCK(I,J),ZPX(I,J)
30138 FORMAT(2I5,F8.2,4F8.4,F7.3,F8.3,F7.3)
30137 CONTINUE
```

```
30136 CONTINUE
      IF(DPY.LT.366) GO TO 30139
      I=29
      DO 30140 J=1,24
      WRITE(4,30141)I,J,ZTMP(366,J),ZRM(366,J),ZCDM(366,J),ZCVM(366,J),Z
     1RADM(366,J),ZLOW(366,J),ZPCK(366,J),ZPX(366,J)
30141 FORMAT(2I5,F8.2,4F8.4,F7.3,F8.3,F7.3)
30140 CONTINUE
30139 CONTINUE
      WRITE(4,30142)
30142 FORMAT(///,32X,'MARCH'    //,2X,'DAY',2X,'HOUR',2X,'TEMP.',3X,'RM',
     16X,'CDM',5X,'CVM',4X,'RADM',4X,'LIOW',4X,'PACK',3X,'RUNOFF'/)
      DO 30143 I=60,90
      DO 30144 J=1,24
      KIJJ=I-59
      WRITE(4,30145)KIJJ,J,ZTMP(I,J),ZRM(I,J),ZCDM(I,J),ZCVM(I,J),ZRADM(
     1I,J),ZLOW(I,J),ZPCK(I,J),ZPX(I,J)
30145 FORMAT(2I5,F8.2,4F8.4,F7.3,F8.3,F7.3)
30144 CONTINUE
30143 CONTINUE
74113 CONTINUE
 8341 IF(DKN(8).EQ.1)GOTO10022
10023 CONTINUE
      IF(DKN(4).NE.1)GOTO5000
      WRITE(4,9945)
 9945 FORMAT(1H1,10X,35HDAILY FLOW DURATION AND ERROR TABLE)
      WRITE(4,9946)
 9946 FORMAT(1H/,10X,13HFLOW INTERVAL5X,5HCASES,3X,8HAV.ERROR,3X,
     116H AVR. ABS. ERROR,3X,14HSTANDARD ERROR)
      SSTER=0.0
      SSERA=0.0
      SSERR=0.0
      SCASE=0.0
      DO9116DD30=1,22
      IF(DD30.EQ.1)FLOO=0.0
      IF(DD30.EQ.2)FLOO=1.0
      FDD30=DD30
      IF(DD30.GT.2)FLOO=EXP((FDD30/2.0)-1.0)
      CAAS=CAS(DD30)
      IF(CAAS.EQ.0.0)WRITE(4,9947)FLOO,CAAS
 9947 FORMAT(1X,13X,F8.1,1H-,F9.1,F12.1,5X,F8.2,5X,F8.2)
      IF(CAAS.EQ.0.0)GOTO9115
      SERACS=SERA(DD30)/CAAS
      SERRCS=SERR(DD30)/CAAS
      IF(CAAS.EQ.1.)WRITE(4,9947)FLOO,CAAS,SERRCS,SERACS
      IF(CAAS.NE.1.)WRITE(4,9947)FLOO,CAAS,SERRCS,SERACS,S(DD30)
 9115 SCASE=SCASE+CAS(DD30)
      IF(SCASE.EQ.0.0)GOTO9116
      SSERR=SSERR+SERR(DD30)
      SSERRO=SSERR/SCASE
      SSERA=SSERA+SERA(DD30)
      SSERAO=SSERA/SCASE
 9116 SSTER=SSTER+S(DD30)
      WRITE(4,9948)SCASE,SSERRO,SSERAO,SSTER
 9948 FORMAT(1H/,22X,F9.1,F12.1,5X,F8.2,5X,F8.2)
      FDPY=DPY
      MEANSY=SABC/FDPY
      MEANAC=SABD/FDPY
      ZACDIF=0.0
      ZSYDIF=0.0
      PRODIF=0.0
      DO9117DD38=1,DPY
```

```
      ACDIF=FLO(DD38)-MEANAC                                              0541
      SYDIF=DR(DD38)-MEANSY                                               0542
      ZACDIF=ZACDIF+ACDIF*ACDIF                                           0543
      ZSYDIF=ZSYDIF+SYDIF*SYDIF                                           0544
 9117 PRODIF=PRODIF+ACDIF*SYDIF                                           0545
      CORCO=PRODIF/SQRT(ZACDIF*ZSYDIF)                                    0546
      WRITE(4,9949)CORCO                                                  0547
 9949 FORMAT(1H/,10X,31HCORRELATION COEFFICIENT (DAILY),3X,F10.4)         0548
 5000 CONTINUE                                                            0549
      IF(DKN(8).EQ.1)GOTO10025                                            0550
      IF(DKN(5).NE.1)GOTO10022                                            0551
COMMENT OUTPUT MAX. RUNOFF,PRECIP. AT END OF YEARS                        0552
      WRITE(4,9950)                                                       0553
 9950 FORMAT(1H/,10X,58HTWENTY HIGHEST CLOCKHOUR RAINFALL EVENTS IN THE   0554
     1WATER YEAR                   )                                      0555
      WRITE(4,9952)(MXRA(DD35),DD35=1,20)                                 0556
 9952 FORMAT(1H/,5X,10F6.3/,5X,10F6.3)                                  080099
      WRITE(4,9951)                                                       0558
 9951 FORMAT(1H/,10X,70HTWENTY HIGHEST CLOCKHOUR OVERLAND FLOW RUNOFF EV  0559
     1ENTS IN THE WATER YEAR)                                             0560
      WRITE(4,9952)(MXRO(DD35),DD35=1,20)                                 0561
10022 CONTINUE                                                            0562
      IF(DKN(6).EQ.0)GOTO5006                                             0563
      WRITE(4,5003)                                                       0564
 5003 FORMAT(1H1,30X,27HDAILY SOIL MOISTURE OUTPUT )                      0565
      CALLDAYOUT(SOILM,HARP,DPY)                                          0566
 5006 CONTINUE                                                            0567
      DDCOM=0                                                             0568
10025 CONTINUE                                                            0569
      IF(DKN(10).EQ.1)GOTO22222                                           0570
      GOTO11111                                                           0571
      END                                                                 0572


      SUBROUTINE  RTVARY(C,CC,CBASE,CHCAP,IZ,IZL,JZ,REC,SHFT,SEX        )  0574
C     THE FOLLOWING SUBROUTINE IS A DUMMY TO REPLACE THE KENTUCKY       080100
C     WATERSHED MODEL SUBROUTINE RTVARY FOR VARYING STREAM ROUTING      080101
C     TIME ACCORDING TO STREAM-FLOW MAGNITUDE BASED ON THE EQUATION     080102
C     V>K*Q**REC PROPOSED BY LEOPOLD AND MADDOX AND WITH THE INTENTION  080103
C     OF MAKING ROUTING A NONLINEAR FUNCTION OF RUNOFF                  080104
C     CARDS 0573 AND 0575 THROUGH 0631 HAVE BEEN REMOVED                080105
      C=C                                                               080106
      RETURN                                                              0632
      END                                                                 0633


      SUBROUTINE  TEST(I,FLO,DR,CFSD,GWF,CFS,C2)                          0635
      IF(FLO.LE.10.0)GOTO133                                              0636
      IF(DR.GT.0.01*CFSD.AND.GWF*CFS.LT.0.25*DR)GOTO20000                 0637
      GOTO133                                                             0638
20000 C2=C2*(ALOG(DR))/(ALOG(FLO))                                        0639
20001 IF(C2.LT.0.25)C2=0.25                                               0640
  133 CONTINUE                                                            0641
      RETURN                                                              0642
      END                                                                 0643
```

```
      SUBROUTINE SNOMEL (SCF,F,KINT,PACK,NEGMEL,OT,COE,B,BPRI,LIOW,OTI,P
     1X,I,J,LIOS,TMAX,TMIN,TDEW,VAP,VW,TDPT,ALANG,MAXRAT,ZPCK,ZTMP,ZLOW,
     1ZPX,ZRM,ZCDM,ZCVM,ZRADM,ZYSNOT)
      REAL KINT,NEGMEL,LIOW,LIOS,MAXRAT
      DIMENSION TMAX(366),TMIN(366),VW(366),VAP(15),TDEW(15),TDPT(366),A
     1LANG(366),ZPCK(366,24),ZTMP(366,24),ZLOW(366,24),ZPX(366,24),ZRM(3
     166,24),ZCDM(366,24),ZCVM(366,24),ZRADM(366,24)
      CVM=0.
      RM=0.
      CDM=0.
      RADM=0.
      VWIND=VW(I)/24.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                   DETERMINATION OF VAPOR PRESSURE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DO99935 KK=1,15
      IF(TDPT(I).GE.100.)GO TO 99936
      IF(TDPT(I).LE.30.)GO TO 99939
      IF(TDEW(KK).GT.TDPT(I))GO TO 99937
99935 CONTINUE
99936 VAPRES=VAP(15)
      GO TO 99938
99939 VAPRES=VAP(1)
      GO TO 99938
99937 VAPRES=VAP(KK-1)+((TDPT(I)-TDEW(KK-1))/(TDEW(KK)-TDEW(KK-1)))*(VAP
     1(KK)-VAP(KK-1))
99938 CONTINUE
      ALNG=ALANG(I)/120.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                    DETERMINATION OF TEMPERATURE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(J.LE.6)GO TO 99901
      IF(J.GE.14)GO TO 99902
      TEMP=TMIN(I)+((FLOAT(J)-6.)/8.)*(TMAX(I)-TMIN(I))
      GO TO 99903
99901 IF(I.EQ.305)GO TO 29633
      IF(I.EQ.1)GO TO 29633
      IF(I.EQ.366) GO TO 29633
      TEMP=TMAX(I-1)-((FLOAT(J)+8.)/14.)*(TMAX(I-1)-TMIN(I))
      GO TO 99903
29633 TEMP=TMIN(I)
      GO TO 99903
99902 IF(I.GE.365.OR.I.EQ.90)GO TO 99904
      IF(I.EQ.59) GO TO 99904
      TEMP=TMAX(I)+((FLOAT(J)-14.)/16.)*(TMIN(I+1)-TMAX(I))
      GO TO 99903
99904 TEMP=TMAX(I)
99903 CONTINUE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                          RAIN OR SNOW TEST
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(I.LE.59.AND.TEMP.LT.35.)GO TO 99905
      IF(I.LE.90.AND.TEMP.LT.32.)GO TO 99905
      IF(I.LE.334.AND.I.GE.305.AND.TEMP.LT.31.)GO TO 99905
      IF(I.LE.365.AND.I.GE.335.AND.TEMP.LT.32.)GO TO 99905
      IF(I.EQ.366.AND.TEMP.LT.35.)GO TO 99905
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                               RAIN
```

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *     WM0354
      IF(PACK.EQ.0.)GO TO 99906                                               WM0201
      IF(QT.LE.0.)GO TO 99906                                                 WM0202
      RATE=0.                                                                 WM0203
      IF(TEMP.GE.32.)RATE=(TEMP-32.)*MAXRAT                                   WM0204
      NEGMEL=NEGMEL+RATE                                                      WM0205
      TOT=PACK*QT                                                             WM0206
      RM=PX*(TEMP-32.)/(144.*QT)                                              WM0207
      IF(RM.LE.0.)RM=0.                                                       WM0208
      GM=0.                                                                   WM0209
      CVM=COE*(TEMP-32.)*VWIND/(6.*QT)                                        WM0210
      IF(CVM.LE.0.)CVM=0.                                                     WM0211
      CDM=B*VWIND*(VAPRES-6.11)/(6.*QT)                                       WM0212
      IF(CDM.LE.0.)CDM=0.                                                     WM0334
      PX=PX+CDM/7.5                                                           WM0213
      RADM=ALNG/(203.2*QT)                                                    WM0214
      IF(J.LE.6)RADM=0.0                                                      WM0215
      IF(J.GE.18)RADM=0.                                                      WM0216
      LIQS=.05*PACK                                                           WM0217
      SMELT=RM+GM+CVM+CDM+RADM                                                WM0218
      IF(NEGMEL.GT.0.)NEGMEL=0.                                               WM0219
      IF(LIQW+SMELT+PX.LE.LIQS-NEGMEL)GO TO 99907                             WM0220
      IF(SMELT+LIQW.GT.PACK-NEGMEL)GO TO 99908                                WM0221
      PACK=PACK-SMELT-NEGMEL                                                  WM0222
      QT=(TOT-SMELT-NEGMEL)/PACK                                              WM0223
      IF(SMELT.GE.TOT-NEGMEL)GO TO 99924                                      WM0224
      SMELT=SMELT+PX+LIQW-LIQS+NEGMEL                                         WM0225
      LIQW=.05*PACK                                                           WM0226
      LIQS=LIQW                                                               WM0227
      NEGMEL=0.                                                               WM0228
99910 PX=SMELT                                                                WM0229
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *     WM0358
C                           SNOW DETAILS ARE STORED                           WM0359
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *     WM0360
      ZPCK(I,J)=PACK                                                          WM0230
      ZTMP(I,J)=TEMP                                                          WM0231
      ZLQW(I,J)=LIQW                                                          WM0232
      ZPX(I,J)=PX                                                             WM0233
      ZRM(I,J)=RM                                                             WM0319
      ZCDM(I,J)=CDM                                                           WM0320
      ZCVM(I,J)=CVM                                                           WM0321
      ZRADM(I,J)=RADM                                                         WM0322
      GO TO 99909                                                             WM0234
99908 SMELT=PACK+PX-CDM/7.5                                                   WM0235
99911 NEGMEL=0.                                                               WM0236
      PACK=0.                                                                 WM0237
      LIQW=0.                                                                 WM0238
      LIQS=0.0                                                                WM0239
      QT=0.                                                                   WM0240
      GO TO 99910                                                             WM0241
99924 SMELT=(PACK+PX+SMELT)*.25                                               WM0242
      IF(PACK+PX+SMELT.GE..04) GO TO 94006                                    WM0335
      SMELT=PACK+PX+SMELT                                                     WM0336
      GO TO 99911                                                             WM0337
94006 NEGMEL=0.                                                               WM0338
      PACK=(PACK+PX+SMELT)*.75                                                WM0339
      QT=.80                                                                  WM0340
      LIQW=.05*PACK                                                           WM0341
      LIQS=LIQW                                                               WM0342
      GO TO 99910                                                             WM0243
99907 LIQW=LIQW+SMELT+PX+NEGMEL                                               WM0244
      PACK=PACK+PX                                                            WM0245
```

```
      IF(TOT.EQ.0..AND.PACK.NE.0.)TOT=QTI*PACK
      QT=TOT/PACK
99914 SMELT=0.
      GO TO 99910
99906 SMELT=PX+PACK
      GO TO 99911
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                                 SNOW
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
99905 PX=PX*SCF
      ZYSNOT=ZYSNOT+PX
      TOT=PACK*QT
      LIQW=LIQW+.10*PX
      RATE=0.
      IF(TEMP.LE.32.)RATE=(32.-TEMP)*MAXRAT
      NEGMEL=NEGMEL-RATE
      IF(-NEGMEL.GE.PACK)NEGMEL=-PACK
      PACK=PACK+PX
      IF(PACK.EQ.0.0)GO TO 99916
      QT=(TQT+PX*QTI)/PACK
99916 LIQS=.05*PACK
      IF(PACK.NE.0.)GO TO 99923
      RADM=0.
      GO TO 99922
99923 IF(QT.LE.0.)GO TO 78666
      RADM=ALNG/(203.2*QT)
78666 IF(J.LE.6)RADM=0.
      IF(QT.LE.0.)RADM=0.
      IF(J.GE.18)RADM=0.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                   CRITERIA FOR REFROZEN MELTWATER
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(TEMP.LT.22..AND.I.GE.305.AND.I.LT.335)NEGMEL=NEGMEL+RADM
      IF(NEGMEL.GE.0.)NEGMEL=0.
      IF(TEMP.LT.22..AND.I.GE.305.AND.I.LT.335)GO TO 99914
      IF(TEMP.LT.25..AND.I.GE.335.AND.I.LE.365)NEGMEL=NEGMEL+RADM
      IF(NEGMEL.GE.0.)NEGMEL=0.
      IF(TEMP.LT.25..AND.I.GE.335.AND.I.LE.365)GO TO 99914
      IF(TEMP.LT.29..AND.I.GE.1.AND.I.LT.60)NEGMEL=NEGMEL+RADM
      IF(NEGMEL.GE.0.)NEGMEL=0.
      IF(TEMP.LT.29..AND.I.GE.1.AND.I.LT.60)GO TO 99914
      IF(TEMP.LT.31..AND.I.GE.60.AND.I.LE.90)NEGMEL=NEGMEL+RADM
      IF(NEGMEL.GE.0.)NEGMEL=0.
      IF(TEMP.LT.31..AND.I.GE.60.AND.I.LE.90)GO TO 99914
      IF(TEMP.LT.29..AND.I.EQ.366)NEGMEL=NEGMEL+RADM
      IF(NEGMEL.GE.0.)NEGMEL=0.
      IF(TEMP.LT.29..AND.I.EQ.366)GO TO 99914
99922 IF(LIQW+RADM.GT.LIQS-NEGMEL)GO TO 99912
      IF(RADM.GE.-NEGMEL)GO TO 99913
      NEGMEL=NEGMEL+RADM+LIQW-LIQS
      LIQW=LIQS
      IF(PACK.EQ.0.0)NEGMEL=0.0
      GO TO 99914
99913 LIQW=LIQW+RADM+NEGMEL
      NEGMEL=0.
      GO TO 99914
99912 SMELT=LIQW+RADM-LIQS+NEGMEL
      IF(SMELT.GE.PACK-LIQW)GO TO 99915
      NEGMEL=0.
      PACK=PACK-SMELT
      LIQS=.05*PACK
      LIQW=LIQS
```

```
      IF(PACK.EQ.0.0)GO TO 99917
      QT=(TOT+PX*QTI-SMELT)/PACK
      IF(QT.LE.0.0)QT=0.0
      GO TO 99910
99917 QT=0.0
      GO TO 99910
99915 SMELT=PACK
      GO TO 99911
99909 RETURN
      END
```

```
      SUBROUTINE DAYOUT(DR,HARP,DPY)
      DIMENSIONDR(366),HARP(12),HARPDR(12)
      INTEGER DD26,DD27,HARP,DPY
      WRITE(4,9916)
 9916 FORMAT(1H/3X3HDAY8X3HOCT6X3HNOV6X3HDEC6X3HJAN6X3HFEB6X
     13HMAR6X3HAPR6X3HMAY6X3HJUN6X3HJUL6X3HAUG5X4HSEPT)
      HARP(3)=0
      DO9107DD27=1,28,1
      IF(MOD(DD27,5).NE.1)GOTO9104
      DO9103II=1,12
      JJ=HARP(II)+DD27
 9103 HARPDR(II)=DR(JJ)
      WRITE(4,9921)DD27,HARPDR(12),(HARPDR(DD26),DD26=1,11)
 9921 FORMAT(1HO,2X,I4,2X,12F9.3)
 9919 FORMAT(1H/,4X,2H31,2X,F9.3,9X,2F9.3,9X,F9.3,9X,F9.3,9X,2F9.3)
      GOTO9107
 9104 DO9105II=1,12
      JJ=HARP(II)+DD27
 9105 HARPDR(II)=DR(JJ)
      WRITE(4,9920)DD27,HARPDR(12),(HARPDR(DD26),DD26=1,11)
 9920 FORMAT(3X,I4,2X,12F9.3)
 9107 CONTINUE
      IF(DPY.NE.366)GOTO9110
      DD27=29
      DR(60)=DR(366)
      DO9109II=1,12
      JJ=HARP(II)+DD27
 9109 HARPDR(II)=DR(JJ)
      WRITE(4,9920)DD27,HARPDR(12),(HARPDR(DD26),DD26=1,11)
      GOTO9111
 9110 CONTINUE
      WRITE(4,9917)DR(302),DR(333),DR(363),DR(29),DR(88),DR(119),DR(149)
     1,DR(180),DR(210),DR(241),DR(272)
 9917 FORMAT(5X,2H29,2X,4F9.3,9X,7F9.3)
 9111 CONTINUE
   57 WRITE(4,9918)DR(303),DR(334),DR(364),DR(30),DR(89),DR(120),DR(150)
     1,DR(181),DR(211),DR(242),DR(273)
 9918 FORMAT(5X,2H30,2X,4F9.3,9X,7F9.3)
      WRITE(4,9919)DR(304),DR(365),DR(31),DR(90),DR(151),DR(212),DR(243)
      HARP(3)=365
      RETURN
      END
```

```
      SUBROUTINE  READ(X)                                              0695
C     THE FOLLOWING SUBROUTINE IS A DUMMY TO REPLACE THE  360          0696
C     SUBROUTINE FOR A COMPILATION CHECK                               0697
      X=X                                                            DM0108
      RETURN                                                           0698
      END                                                              0699
```

```
      SUBROUTINE DYLOOP                                                0701
       LOGICAL SHFT                                                    0702
      REAL MINH,LOS,K,KV4,KS,KSC,KSF,K24EL,K24L,ITI,LKV4,MEANAC        0703
      REALINTF,LZI,LZSN,LNRAT,KV24,K3,K1,LSF,KRN,LIOW,KK24,KK4         0704
      REALLKK4,LZS,MEANSY,MSEVEP,IPACK,IRC4,IRC                        0705
      REALLIRC4,ISEP,LZS1,MINTLA,MINTLS,NN,NNU,L,LNRATM                0706
      REALMXRO,MXRA,LZSA,MSEVAP,MAXRAT,IFACTR,KINT,NEGMEL,IDNS         0707
      REAL LIOS                                                      0M0079
      INTEGERDD32,DD45,DD25,DD27,DD30,DD38,DD36,DD37,DD35,DD48,DD26    0708
      INTEGER DD15,DD24,DD33,DD34,DKN,ZIP,DD23,DD13,YR,Z,FA            0709
      INTEGER TCONC, TINC, YRDET                                     LV0100
      INTEGERCN,DDCOM,DDL,DDLM,DDYEAR,DDYR1,DDYR2,DDZ                  0710
      INTEGERDPY,DAY,HOUR,HARP,HAAP,SGRTT,SGRT,OOO,OOW,ST              0711
      COMMON A,AHOUR,AFTR,BASFLW,CC(99),C(99),CAS(22),CY,C3,CX,C2,CB,CFS 0712
     1,CHCAP,CKSF,C2L,C2A(12),DE,D4F,DDZ,DD23,DEPTH,DKN(20),DDYR2,DDYR1, DM0318
     2DDLM,DDL,DD13,DPY,DEC,DD24,D23,DAY,DIRRNF,DD33,DD34,DEEPL,DR(366),  0714
     3DEN,EVCR(12),E(366),EP,ETEMP,ETL,EPX,EDF,EN,EMIN,ENTRUZ,ENTRLZ,   0725
     4ELH,EPXM,FA,F,F3,F1,FLO(366),GWF,GWS,GWSA(12),HRM,HRM12,HARP(12),I  0716
     5NO,     ICNT,IZL,IPACK,I,I1,I2,INTF,     ISEP,J,J2,JZ,KSF,K(366),K LV0101
     6JI,KRN,K24L,KS,KSC,K24FL,K3,LZSA(12),LOS,LIOW,LKV4,LSF,LNRAT,LZS,L  0718
     7NRATM,LZSN,LZI,LIRC4,LKK4,MSN2,MSN1,MSEVEP,MXRO(21),MXRA(21),MINH,  0719
     8MODDAY,MSEVAP(12),MINTLA(12),MINTLS,NXIN,NXDAY(100),NEGMEL,OVFLST,  0720
     9OUTFLW,PAR,PRE,PR,P3,P4,PX,PACK,P1SUM,PREC(366),P1(366,24),PA      0721
       COMMON OOO(20)                                                  0722
      COMMON       OOO(15),ROFF,ROOUT,R(99),RIGIW,RES,ROS,PGX,RX,RECE,SIN 0723
     1T,SABC,SABD,SABM,SGRTT,SGRT,SSGR,SPRM,SPR,SPRA(12),SPETA(12),SINTA  0724
     2(12) ,     SGWFA(12),SPRMA(12),SAETA(12),SAET,SPET,SSEP,     SFX,SS 0725
     3GWF,SUMTR,SFM,SF(366),SEVAP,SDEN,SROS,SSF,SHRO,SRGX,SEP,SRC,SGW,SH  0726
     4FT,SF,SDR(366),SDIV(366),SOILM(366),SERR(22),SERA(22),SOER(22),S(2  0727
     52),SGWA(12),TMAX(366),TMIN(366),TOTFLW,TR(24),TRS(100,24),TIMNOX,T  0728
     6ONE(12),TONM(12),TOND(12),USRC,UZSN,UZS,UZI,UROS,UPR,URES,UOF,UOFC  0729
     7,UZSNA(12),UZSA(12),WSG,ZIP,Z,YR  ,ENA(12),SREMN,ZYSNOT            0730
      COMMON SCF,KINT,OT,COE,B,BPRI,OTI,LIOS,TDEW(15),VAP(15),VM(366),TO DM0076
     1PT(366),ALANG(366),MAXRAT,ZPCK(366,24),ZTMP(366,24),ZLOW(366,24),Z DM0311
     1PX(366,24),ZRM(366,24),ZCOM(366,24),ZCVM(366,24),ZRAD (366,24)    DM0312
       COMMON N, ELDIF, OVLOST, EF, ERR, LZSN                          0731
      COMMON TCONC,TINC,NINC,YRDET,XUNIT(10),YUNIT(10),XORG(10),YORG(10) LV0102
     1,IOUT(10),INUM(10),MM,FRAC                                     LV0103
       COMMON CBASE(99), IZ, REC, CFSO                                 0732
      COMMON FACTOR,VOLUME,AREA                                      SM0013
      FACTOR = 0.0                                                   SM0014
      ASSIGN 11 TO MSN1                                                0733
      ASSIGN 10003 TO MSN2                                             0734
      IF(DD13.LE.0) GO TO 10003                                        0735
   15 I1=274                                                           0736
      I2=365                                                           0737
      KJI=0                                                            0738
   10  KJI=KJI+1                                                       0739
      I=I1                                                             0740
 5250 CONTINUE                                                         0741
      GO TO MSN1,(11,12,13)                                            0742
```

```
  212 I=I+1
      IF(I.LE.I2)GOTO5250
      GO TO (1001,1002,1003,1004),KJI
 1001 I1=1
      I2=59
      GO TO 10
 1002 IF(DPY.LT.366) GO TO 1003
      I1=366
      I2=DPY
      GO TO 10
 1003 I1=60
      I2=273
      KJI=3
      GO TO 10
 1004 GO TO MSN2,(10003,21,54)
   11 IF(DD13.EQ.0) GO TO 212
      DO 213 J = 1,24
      P1SUM=P1SUM+P1(I,J)
      IF(J.NE.SGRTT) GO TO 213
      IF(P1SUM.LE.0.0) GO TO 2133
      IF(SGRT.EQ.0)  DDL=I
      K(DDL)=(PREC(I)*WSG+P1SUM*(1.0-WSG))/P1SUM
      E(DDL) = 0.5*F(DDL)
      IF(SGRT.NE.0)  DDL = I
      P1SUM=0.0
      GO TO 213
 2133 IF(PREC(I).LE.0.0) GO TO 2213
      DO 2134 J2=1,SGRTT
 2134 P1(I,J2)=(WSG*PREC(I))/SSGR
 2213 IF(SGRT.NE.0) DDL = I
  213 CONTINUE
      GO TO 212
10003 FA = 1
      DDLM=273
      SPRM=0.0
      SPR=0.0
      SSGWF=0.0
      SABM=0.0
      SABD=0.0
      SRFSN=0.
      SABC=0.0
      GO TO 21
   12 GO TO 212
   21 WRITE(4,301) (QQQ(N),N=1,20)
  301 FORMAT(1H1,10X,20A4)
      WRITE(4,302) (QQQ(N),N=1,15),DDYR1,DDYR2
  302 FORMAT(1H0,15A4,3X,13HWATER YEAR 19I2,1H-I2/,2X,36HKY. VERSION STA
     1NFORD WATERSHED MODEL)
      WRITE(4,303)
  303 FORMAT(8H0OCTOBER)
      IF(OKN(18).EQ.1)WRITE(4,9821)
 9821 FORMAT(1H ,6X,4HSSEP,6X,4HISEP,7X,2HEN,6X,4HUZSN,6X,3HUZS,8X,3HGWS
     1,7X,3HSGW,6X,4HSINT,6X,4HSRGX,5X,5HSSGWF,7X,3HLOS/)
10004 ASSIGN 13 TO MSN1
      ASSIGN 54 TO MSN2
      GO TO 15
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                     BEGIN THE DAY LOOP
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
   13 SUMTR=0.0
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                    COMPUTE   LAKE   EVAPORATION
```

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      EP=EVCR(FA)*E(I)
      ETEMP = EP
      SFM=0.0
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     COMPUTATION OF VARIABLE GROUND WATER RECESSION CONSTANTS
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(DR(I-1).LE.20.0) LKK4=1.-(.732135)**(1.0/96.0)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                         EVAPOTRANSPIRATION  ADJUSTMENTS
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
   22 DO215J=1,24
      IF((DD13.EQ.0).AND.(P1(I,J).NE.0.0).AND.(EP.EQ.ETEMP))EP=0.5*EP
   30 IF(J.EQ.SGRT+1)KRM=K(I)
      IF(J.EQ.1)ELH=0.0
      IF(J.EQ.9)ELH=(ETL*EP)/12.0
      IF(ELH.GT.GWF)ELH=GWF
      IF(J.EQ.21)ELH=0.0
      PX=KRM*P1(I,J)
      SPR=SPR+PX
      IF(I.LE.90 .OR. I.GE.305) GO TO 98926
      IF(I.EQ.91.AND.J.EQ.1.AND.PACK.NE.0.)WRITE(6,98928)PACK
98928 FORMAT(1X,'PACK NOT 0.0',10X,'PACK EQUALS',F10.7,1X,'INCHES')
      PX=PX+PACK
      PACK=0.
      GO TO 24
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                        ENTER SNOWMELT SUBROUTINE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
98926 IF(DKN(7).EQ.1) CALL SNOMEL (SCF,F,KINT,PACK,MEGMEL,DT,COE,B,BPRI,
     1LIQW,OTI,PX,I,J,LIQS,TMAX,TMIN,TDEW,VAP,VW,TOPT,ALANG,MAXRAT,ZPCK,
     1ZTMP,ZLOW,ZPX,ZRM,ZCDM,ZCVM,ZRADM,ZYSNOT)
   24 SPRM=SPRM+PX
   23 SROS=0.0
      SSF=0.0
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     VARIABLE  TIME  ACCOUNTING  AND ROUTING  LOOP
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DO14DD23=1,MINC
      P4=0.0
      P3=0.0
      ROS=0.0
      UROS=0.0
      SHRD=0.0
      RGX=0.0
      UPR=0.0
      PR=FRAC*PX
      IF(PR.GT.0.0)GOTO10005
      IF(RES.GT.0.0)GOTO10006
      IF(SRGX.GT.0.0)GOTO10007
      IF(DDZ.GT.0)GOTO10008
      RIGIO=0.0
      IF(LSF.GT.0.0)GOTO10010
      GOTO5166
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                          RAINFALL  UPPER  ZONE  INTERACTION
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
10005 IF(PR.GE.EPX)GOTO34
      UZS=UZS+PR*PAR
      EPX=EPX-PR
      P3=0.0
       P4=0.0
```

```
      GOTO10006
   34 P3=PR-EPX
      UZS=UZS+EPX*PAR
      EPX=0.0
      LNRAT=LZS/LZSN
      IF(I.LE.335.AND.I.GE.183) FACTOR = (VOLUME*12.0)/(AREA*640.0)
      IF(I.GE.336.OR.I.LE.182) FACTOR = -(VOLUME*12.0)/(AREA*640.0)
      UZSN = EDF*SFP+CX*EXP(-2.7*LNRAT)+FACTOR
      IF(UZSN.LT.0.25)UZSN=0.25
      UZI=2.0*ABS(UZS/UZSN-1.0)+1.0
      PRE=(1.0/(1.0+UZI))**UZI
      IF(UZS.GT.UZSN)PRE=1.0-PRE
      P4=P3*PRE
      UZS=UZS+P3-P4
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                            LOWER  ZONE  AND  GW  INFILTRATION
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
10006 LNRAT=LZS/LZSN
      LNRATM=4.0*LNRAT
      IF(LNRAT.LE.1.0)GOTO79
      LNRATM=4.0+2.0*(LNRAT-1.0)
      IF(LNRAT.LE.2.0)GOTO79
      LNRATM=6.0
   79 P4=P4+RES
      D4F=FRAC*EM*C2*CB/(2.0**LNRATM)
      C3=CY*2.0**LNRAT
      RX=P4*P4/(2.0*D4F*C3)
      SHRD=P4*P4/(2.0*D4F)
      IF(P4.GE.D4F)SHRD=P4-0.5*D4F
      IF(P4.GE.D4F*C3)RX=P4-0.5*D4F*C3
      RGX=SHRD-RX
      IF((RX-RES).GT.0.0)GOTO80
      DE=(RES+RX)/2.0
      GOTO81
   80 DE=DEC*((RX-RES)**0.6)
   81 IF((RES+RX).GT.(2.0*DE))DE=0.5*(RES+RX)
      IF((RES+RX).LE.0.001)GOTO82
      ROS=FRAC*SRC*(((RES+RX)*0.5)**1.67)*((1.0+0.6*((RES+RX)/
     1(2.0*DE))**3.0)**1.67)
      IF(ROS.GT.(0.75*RX))ROS=0.75*RX
   82 IF(A.EQ.0.0)GOTO87
   83 UPR=P3+URES
      IF((UPR-URES).GT.0.0)GOTO84
      UDE=(URES+UPR)/2.0
      GOTO85
   84 UDE=UDEC*((UPR-URES)**0.6)
   85 IF((URES+UPR).GT.(2.0*UDE))UDE=0.5*(URES+UPR)
      IF((URES+UPR).LE.0.01)GOTO87
      UROS=FRAC*USRC*(((URES+UPR)*0.5)**1.67)*((1.0+0.6*((URES+UPR
     1)/(2.0*UDE))**3.0)**1.67)
      IF(UROS.GT.UPR)UROS=UPR
   87 SROS=SROS+PA*ROS+A*UROS+P3*ETL
      URES=UPR-UROS
      RES=RX-ROS
      IF(RES.GE.0.001)GOTO36
      LZS=LZS+RES
      RES=0.0
      UROS=UROS+URES
      URES=0.0
   36 LZI=1.5*ABS(LZS/LZSN-1.0)+1.0
      PRE=(1.0/(1.0+LZI))**LZI
      IF(LZS.LT.LZSN)PRE=1.0-PRE*(LZS/LZSN)
```

```
      F3=PRE*(P4-SHRD)
      F1=(1.0-PRE)*(P4-SHRD)*(1.0-K24L)*PA
      SGW=SGW+F1
      GWS=GWS+F1
      LZS=LZS+F3
      SRGX=SRGX+RGX*PA
10007 INTF=LIRC4*SRGX
      SINT=SINT+INTF
C        NO CARD NUMBER 927
      SRGX=SRGX-INTF
      IF(SRGX.GE.0.0001)GOTO37
      LZS=LZS+SRGX
      SRGX=0.0
   37 R(1)=PA*ROS+P3*FTL+A*URGS+INTF
       ROOUT=R(1)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                       ROUTING
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
10008 IF(DKN(12).NE.1)GOTO38
      ROFF=ROFF+FRAC*R(1)
      IF(DD23.NE.NINC)GOTO10010
      R(1)=ROFF
   38 RIGIO=0.0
      DD24=Z
      IF(DKN(13).EQ.1)DD24=JZ
   41 IF(DD24.LT.1)GOTO39
      ROFF=R(DD24)
      IF(ROFF.GT.0.0)GOTO8911
      GOTO5483
 8911 RIGIO=RIGIO+ROFF*C(DD24)
      IF(DKN(13).EQ.1.AND.SHFT.AND.DD24.GE.2)RIGIO=
     1RIGIO+ROFF*CC(DD24-1)
      R(DD24+1)=ROFF
      GOTO40
 5483 R(DD24+1)=0.0
   40 DD24=DD24-1
      GOTO41
   39 IF(ROFF.GT.0.0)DDZ=Z
      DDZ=DDZ-1
      R(1)=0.0
      ROFF=0.0
10010 IF(KS.LE.KSC)KS=KSC
      SF=RIGIO-KS*(RIGIO-LSF)
      LSF=SF
      IF(LSF.LT.0.000001)LSF=0.0
      SFX=(60./FLOAT(TINC)*SF+GWF-ELH)*CFS
      IF(DKN(13).EQ.1.AND.((SFX.GT.0.1*CHCAP).OR.(JZ.NE.IZL)))
     1CALLRTVARY(C,CC,CBASE,CHCAP,IZ,IZL,JZ,KFC,SHFT,SFX)
      IF(SFX.LE.0.5*CHCAP)KS=KSC
     0IF((SFX.GT.0.5*CHCAP).AND.(SFX.LT.2.0*CHCAP))KS=KSC+(KSF-KSC)*
     1((SFX-0.5*CHCAP)/(1.5*CHCAP))**3
      IF(SFX.GE.2.0*CHCAP)KS=KSF
      IF(SFX.LE.SFM)GOTO42
      D23=DD23
      AHOUR=J
      HRM=(AHOUR-1.0)+0.15*D23
      IF(DD23.EQ.4)HRM=J
      SFM=SFX
   42 SSF=SSF+SF
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                    STORM   OUTPUT   REQUESTED   BY   DKN(1)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
 5166 IF(DKN(1).NE.1)GOTO10009                                            0981
      IF(I.NE.IOUT(MM))GOTO10009                                          LV0117
      IF(J.EQ.1.AND.DD23.EQ.1)WRITE(4,128)                                0983
  128 FORMAT(1H//,21X,19HRAINFALL DEPOSITION,12X,16HMOISTURE STORAGE,     0984
     1 14X,17HSTREAMFLOW ORIGIN,6X,14HSTREAM OUTFLOW/2X,                  0985
     2117HDY HR PD  RAIN ENTRUZ ENTRLZ INTFST OVFLST       UZS    LZS   S 0986
     3RGX OVLDST   DIRRNF INTFRF BASFLW TOTFLW INCHES      CFS)           0987
      DAY=MOD(I,DDLM)                                                     0988
      ENTRUZ=PR-P4                                                        0989
      ENTRLZ=P4-SHRO                                                      0990
      RGX=ABS(RGX)                                                        0991
      OVFLST=RX                                                           0992
      OVLDST=RES*PA+URES*A                                                0993
      DIRRNF=ROS*PA+UROS*A                                                0994
      BASFLW=FRAC*(GWF-ELH)                                               LV0118
      TOTFLW=ROOUT+BASFLW                                                 0996
      ROOUT=0.0                                                           0997
      IF(LSF.LE.0.0)SFX=(GWF-ELH)*CFS                                     0998
      OUTFLW=FRAC*SFX/CFS                                                 LV0119
      IF(I.EQ.366) DAY=29                                                 JM0004
      WRITE(4,129) DAY,J,DD23,PR,ENTRUZ,ENTRLZ,RGX,OVFLST,UZS,LZS,SRGX,   1000
     1 OVLDST,DIRRNF,INTF,BASFLW,TOTFLW,OUTFLW,SFX                        1001
  129 FORMAT(1X,I2,1X,I2,1X,I2,5(1X,F6.4),2X,4(1X,F6.3),2X,5(1X,F6.4),    LV0120
     1 1X,F7.3)                                                           LV0121
      IF(DKN(20).EQ.0) GOTO4004                                           LV0122
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * **  LV0123
C        PLOTTING  STORM  OUTPUT  REQUESTED  BY  DKN(19)                  LV0124
      HRDEC=FLOAT(J-1)+FLOAT(DD23)*FRAC                                   LV0125
      XLEN=((FLOAT(ICNT)*24.+HRDEC)-XORG(MM))/XUNIT(MM)                   LV0126
      YLEN=(SFX-YORG(MM))/YUNIT(MM)                                       LV0127
      CALL PLOT(XLEN,YLEN,2)                                              LV0128
 4004 IF(J.EQ.24.AND.DD23.EQ.NINC)GOTO19009                               LV0129
      GOTO10009                                                           LV0130
19009 ICNT=ICNT+1                                                         LV0131
      IF(INUM(MM).EQ.ICNT) GOTO10009                                      LV0132
      IOUT(MM)=IOUT(MM)+1                                                 LV0133
      IF(IOUT(MM).EQ.366)IOUT(MM)=1                                       LV0134
      IF(IOUT(MM).EQ.60.AND.DPY.EQ.366) IOUT(MM)=366                      LV0135
      IF(IOUT(MM).EQ.367) IOUT(MM)=60                                     LV0136
10009 CONTINUE                                                            LV0137
      IF(EPX.LT.(FRAC*EPXM))EPX=EPX+E(I)*(1./(24.*60./FLOAT(TINC)))       LV0138
   14 CONTINUE                                                            LV0139
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   LV0140
C     END  OF  VARIABLE  ROUTING  TIME  LOOP                              LV0141
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   LV0142
      IF(DKN(5).NE.1)GOTO43                                               1018
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   1019
C           HOURLY  OVERLAND  FLOW  AND  RAINFALL  SORTING                1020
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   1021
      IF(SROS.LE.0.0)GOTO10011                                            1022
      DD33=20                                                             1023
   45 IF(DD33.LT.1)GOTO5931                                               1024
      IF(SROS.GT.MXRO(DD33))GOTO44                                        1025
      GOTO5480                                                            1026
   44 MXRO(DD33+1)=MXRO(DD33)                                             1027
      GOTO5481                                                            1028
 5480 MXRO(DD33+1)=SROS                                                   1029
      GOTO10011                                                           1030
 5481 DD33=DD33-1                                                         1031
      GOTO45                                                              1032
 5931 MXRO(1)=SROS                                                        1033
10011 IF(PX.LE.0.0)GOTO43                                                 1034
```

```
      DD34=20
   47 IF(DD34.LT.1)GOTO5831
      IF(PX.GT.MXRA(DD34))GOTO46
      MXRA(DD34+1)=PX
      GOTO43
   46 MXRA(DD34+1)=MXRA(DD34)
      DD34=DD34-1
      GOTO47
 5831 MXRA(1)=PX
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                            ADDING  GROUNDWATER  FLOW
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
   43 GWF=SGW*LKK4*(1.0+LKV4*GWS)
      SGW=SGW-GWF
      SSGWF=SSGWF+GWF-FLH
      TR(J)=(SSF+GWF-FLH)*CFS
      IF(TR(J).LT.0.0)TR(J)=0.0
      SUMTR=SUMTR+TR(J)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                            DRAINING  OF  UPPER  ZONE  STORAGE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DEEPL=(UZS/UZSN)-(LZS/LZSN)
      IF(DEEPL.LE.0.0)GOTO48
      LNRAT=LZS/LZSN
      RECE=0.003*CB*UZSN*DEEPL**3.0
      UZS=UZS-RECE
      LZI=1.5*ABS(LNRAT-1.0)+1.0
      PRE=(1.0/(1.0+LZI))**LZI
      IF(LZS.LT.LZSN)PRE=1.0-PRE*LNRAT
      F1=(1.0-PRE)*RECE*(1.0-K24L)*PA
      F3=PRE*RECE
      LZS=LZS+F3
      SGW=SGW+F1
      GWS=GWS+F1
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                            4 PM  ADJUSTMENTS  OF  VARIOUS  VALUES
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
   48 IF(J.NE.16)GOTO215
      SEP=0.9*(SEP+EP)
      SSEP=0.96*(SSEP+EP)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                            INFILTRATION  CORRECTION
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      EN=(SSEP/ISEP)**EF
      IF(EN.LT.EMIN) EN=EMIN
      GWS=0.97*GWS
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                         EVAP-TRANS  LOSS  FROM  GROUNDWATER
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      LOS=SGW*K24EL*EP*PA
      SGW=SGW-LOS
      GWS=GWS-LOS
      IF(GWS.LT.0.0)GWS=0.0
      IF(EP.EQ.0.0)GOTO215
      SPET=SPET+EP
      IF(EP.GE.UZS)GOTO49
      UZS=UZS-EP
      SAET=SAET+EP
      GOTO215
   49 EP=EP-UZS
      SAET=SAET+UZS
      UZS=0.0
```

```
      LNRAT=LZS/LZSN
      IF(EP.GE.K3*LNRAT)GOTO50
      AETR=EP*(1.0-EP/(2.0*K3*LNRAT))
      GOTO214
   50 AETR=0.5*K3*LNRAT
  214 LZS=LZS-AETR
      SAET=SAET+AETR
  215 CONTINUE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                           END  OF  THE  HOUR  LOOP
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(DKN(18).EQ.1)WRITE(4,9822) SSEP,ISEP,EN,UZSN,UZS,GWS,SGW,SINT,S
     1RGX,SSGWF,LOS
 9822 FORMAT(1X,11F10.3)
      DR(I)=SUMTR/24.0
      IF(DKN(8).EQ.1)SDR(I)=SDR(I)+DR(I)
      IF(DKN(11).EQ.1)DR(I)=DR(I)+SDIV(I)
      SABC=SABC+DR(I)
      IF(YR.NE.99)GOTO51
      DR(I)=SDR(I)+SDIV(I)
      GOTO10012
   51 IF(DKN(8).EQ.1)GOTO10013
10012 SABD=SABD+FLO(I)
      IF(I.LE.90.OR.I.GE.305)SRFSN=SRFSN+FLO(I)
      SABM=SABM+DR(I)
      IF(DKN(6).EQ.1)SOILM(I)=LZS
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                              STORE  ERRORS  AND  FLOW   DURATIONS
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(DKN(4).NE.1)GOTO10013
      ERR=DR(I)-FLO(I)
      IF(FLO(I).LT.1.0)IND=1.0
      IF(FLO(I).GE.1.0)IND=2.0*ALOG(FLO(I))+2.0
      CAS(IND)=CAS(IND)+1.0
      SERR(IND)=SERR(IND)+ERR
      SERA(IND)=SERA(IND)+ABS(ERR)
      SOER(IND)=SOER(IND)+ERR*ERR
      S(IND)=0.0
     OIF(CAS(IND).GT.1.0) S(IND)=SQRT(ABS((SOER(IND)-SERR(IND)**2/CAS(IN
     1D))/(CAS(IND)-1.0)))
10013 IF(SFM.LE.MINH)GOTO5686
      IF(I.EQ.366)DDLM=337
      MODDAY=MOD(I,DDLM)
      WRITE(4,9904)MODDAY,(TR(J),J=1,12)
 9904 FORMAT(1H/,1X/,1X,I4,2X,2HAM,1X,6F8.1,3X,6F8.1)
      WRITE(4,9905)(TR(J),J=13,24),DR(I)
 9905 FORMAT(1HJ,6X,2HPM,1X,6F8.1,3X,7F8.1)
       IF(HRM.LT.12.0)GOTO52
      HRM12=HRM-12.0
      WRITE(4,8200)SFM,HRM12
 8200 FORMAT(1H/,10X,8HMAXIMUM=F8.1,2X,6HC.F.S.5X,4HTIME3X,F5.2,2X,4HP.M
     1.)
      GOTO5686
   52 WRITE(4,9906)SFM,HRM
 9906 FORMAT(1H/,10X,8HMAXIMUM=F8.1,2X,6HC.F.S.5X,4HTIME3X,F5.2,2X,4HA.M
     1.)
 5686 IF(DKN(8).NE.1)GOTO53
      MXIN=MXIN+1
      IF(MXIN.GT.100)GOTO53
      DO216J=1,24
  216 TRS(MXIN,J)=TRS(MXIN,J)+TR(J)
      MXDAY(MXIN)=I
```

```
      GOTO10014
   53 IF(DKN(2).EQ.1) CALL TEST(I,FLO(I),DR(I),CFSD,GWF,CFS,C2)
      MODDAY=MOD(I,DDLM)
      IF(DKN(2).EQ.1.AND.C2.NE.C2L)WRITE(4,9908)MODDAY,C2
 9908 FORMAT(3X,I4,4X,3HC2=F7.2)
      C2L=C2
10014 IF(I.EQ.366)DDLM=337
      MODDAY=MOD(I,DDLM)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C                             MONTHLY   SUMMARY   STORAGE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(I.NE.HARP(FA))GOTO212
      TONE(FA)=SABC
      TONM(FA)=SABM
      TOND(FA)=SABD
      GWSA(FA)=GWS
      SPRA(FA)=SPR
      SPR=0.0
      SPRMA(FA)=SPRM
      SPRM=0.0
      SGWFA(FA)=SSGWF
      SSGWF=0.0
      SINTA(FA)=SINT
      SINT=0.0
      SPETA(FA)=SPET
      SPET=0.0
      SAETA(FA)=SAET
      SAET=0.0
      MSEVAP(FA)=MSEVEP
      MSEVEP=0.0
      MINTLA(FA)=MINTLS
      MINTLS=0.0
      SGWA(FA)=SGW
      C2A(FA)=C2
      UZSN=EDF*SEP+CX*EXP(-2.7*LZS/LZSN)
      IF(UZSN.LT.0.25)UZSN=0.25
      UZSNA(FA)=UZSN
      UZSA(FA)=UZS
      EMA(FA)=EM
      LZSA(FA)=LZS
      IF(FA.EQ.5)HARP(5)=59
      DDLM=HARP(FA)
100150IF(FA.NE.0) GO TO(10501,10502,10503,10504,10505,10506,10507,10508
     1,10509,10510,10511,10016),FA
10501 WRITE(4,8000)
 8000 FORMAT(1H/,8HNOVEMBER)
      GOTO10016
10502 WRITE(4,8010)
 8010 FORMAT(1H/,8HDECEMBER)
      GOTO10016
10503 WRITE(4,8020)
 8020 FORMAT(1H/,7HJANUARY)
      GOTO10016
10504 WRITE(4,8030)
 8030 FORMAT(1H/,8HFEBRUARY)
      GOTO10016
10505 WRITE(4,8040)
 8040 FORMAT(1H/,5HMARCH)
      GOTO10016
10506 WRITE(4,8050)
 8050 FORMAT(1H/,5HAPRIL)
      GOTO10016
```

```
10507 WRITE(4,8060)
 8060 FORMAT(1H/,3HMAY)
      GOTO10016
10508 WRITE(4,8070)
 8070 FORMAT(1H/,4HJUNE)
      GOTO10016
105090 WRITE(4,8080)
 8080 FORMAT(1H/,4HJULY)
      GOTO10016
10510 WRITE(4,8090)
 8090 FORMAT(1H/,6HAUGUST)
      GOTO10016
10511 WRITE(4,8100)
 8100 FORMAT(1H/,9HSEPTEMBER)
10016 FA=FA+1
C     IF(ZIP.EQ.1)GOTO10017
      GOTO212
C    END OF DAY LOOP
   54 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LOGPLT(DR,DPY,DRORG,DELDR,DELT)
      DIMENSION DR(366)
      INTEGER DPY
      FN(T)=(ALOG10(T+.01)-DRORG)/DELDR
      TIME=0.
      CALL PLOT(TIME,FN(DR(274)),3)
      DO 8000 I=275,365
      TIME=TIME+DELT
      CALL PLOT(TIME,FN(DR(I)),2)
 8000 CONTINUE
      DO 8010 I=1,59
      TIME=TIME+DELT
      CALL PLOT(TIME,FN(DR(I)),2)
 8010 CONTINUE
      IF(DPY-366)8030,8020,8020
 8020 TIME=TIME+DELT
      CALL PLOT(TIME,FN(DR(366)),2)
 8030 DO 8040 I=60,273
      TIME=TIME+DELT
      CALL PLOT(TIME,FN(DR(I)),2)
 8040 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LOGPL(DR,DPY,DRORG,DELDR,DELT,DL,SL)
      DIMENSION DR(366)
      INTEGER DPY
      FN(T)=(ALOG10(T+.01)-DRORG)/DELDR
      K=-1
      TIME=0.
      CALL DASHC(TIME,FN(DR(274)),K,DL,SL)
      DO 8000 I=275,365
```

```
      TIME=TIME+DELT
      CALL DASHC(TIME,FN(DR(I)),K,DL,SL)
 8000 CONTINUE
      DO 8010 I=1,59
      TIME=TIME+DELT
      CALL DASHC(TIME,FN(DR(I)),K,DL,SL)
 8010 CONTINUE
      IF(DPY-366)8030,8020,8020
 8020 TIME=TIME+DELT
      CALL DASHC(TIME,FN(DR(366)),K,DL,SL)
 8030 DO 8040 I=60,273
      TIME=TIME+DELT
      CALL DASHC(TIME,FN(DR(I)),K,DL,SL)
 8040 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ARITHP(DR,DPY,DRRORG,DDELDR,DELT)
      DIMENSION DR(366)
      INTEGER DPY
      FN(T)=(T-DRRORG)/DDELDR
      TIME=0.
      CALL PLOT(TIME,FN(DR(274)),3)
      DO 8000 I=275,365
      TIME=TIME+DELT
      CALL PLOT(TIME,FN(DR(I)),2)
 8000 CONTINUE
      DO 8010 I=1,59
      TIME=TIME+DELT
      CALL PLOT(TIME,FN(DR(I)),2)
 8010 CONTINUE
      IF(DPY-366)8030,8020,8020
 8020 TIME=TIME+DELT
      CALL PLOT(TIME,FN(DR(366)),2)
 8030 DO 8040 I=60,273
      TIME=TIME+DELT
      CALL PLOT(TIME,FN(DR(I)),2)
 8040 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ARITH(DR,DPY,DRRORG,DDELDR,DELT,DL,SL)
      DIMENSION DR(366)
      INTEGER DPY
      FN(T)=(T-DRRORG)/DDELDR
      K=-1
      TIME=0.
      CALL DASHC(TIME,FN(DR(274)),K,DL,SL)
      DO 8000 I=275,365
      TIME=TIME+DELT
      CALL DASHC(TIME,FN(DR(I)),K,DL,SL)
 8000 CONTINUE
      DO 8010 I=1,59
      TIME=TIME+DELT
```

```
      CALL DASHC(TIME,FM(DR(I)),K,DL,SL)
 8010 CONTINUE
      IF(DPY-366) 8030,8020,8020
 8020 TIME=TIME+DELT
      CALL DASHC(TIME,FM(DR(366)),K,DL,SL)
 8030 DO 8040 I=60,273
      TIME=TIME+DELT
      CALL DASHC(TIME,FM(DR(I)),K,DL,SL)
 8040 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DASHC(X,Y,NPOIN ,DASH,SPACE)
      IF(NPOIN +1)2,2,3
    2 NPOIN =NPOIN +2
      OVERS=0
      OVERD=0
      IPEN=1
      XO=X
      YO=Y
      CALL PLOT(XO,YO,1)
      RETURN
    3 NPOIN =NPOIN +1
      DX=X-XO
      DY=Y-YO
      R=SQRT(DX**2+DY**2)
      IF(R)16,16,17
   17 SINTH=DY/R
      COSTH=DX/R
   10 IF(R)16,16,15
   15 IF(IPEN)8,5,5
    5 IF(OVERD)11,11,12
   12 IF(R-OVERD)19,18,18
   19 OVERD=OVERD-R
      GO TO 20
   18 XO=OVERD*COSTH+XO
      YO=OVERD*SINTH+YO
      CALL PLOT(XO,YO,2)
      R=R-OVERD
      OVERD=0
      IPEN=(-1)
      GO TO 10
   11 IF(R-DASH)6,4,4
    4 XO=DASH*COSTH+XO
      YO=DASH*SINTH+YO
      CALL PLOT(XO,YO,2)
      R=R-DASH
      IPEN=(-1)
      GO TO 10
    8 IF(OVERS)13,13,14
   14 IF(R-OVERS)22,21,21
   22 OVERS=OVERS-R
      GO TO 23
   21 XO=OVERS*COSTH+XO
      YO=OVERS*SINTH+YO
      CALL PLOT(XO,YO,1)
      R=R-OVERS
      OVERS=0
```

```
      IPEN=1                                                            DBC256
      GO TO 10                                                          DBC257
   13 IF(R-SPACE)9,7,7                                                  DBC258
    7 XO=SPACE*COSTH+XO                                                 DBC259
      YO=SPACE*SINTH+YO                                                 DBC260
      CALL PLOT(XO,YO,1)                                                DBC261
      R=R-SPACE                                                         DBC262
      IPEN=1                                                            DBC263
      GO TO 10                                                          DBC264
    6 OVERD=DASH-R                                                      DBC265
   20 CALL PLOT(X,Y,2)                                                  DBC266
      XO=X                                                              DBC267
      YO=Y                                                              DBC268
      RETURN                                                            DBC269
    9 OVERS=SPACE-R                                                     DBC270
   23 CALL PLOT(X,Y,1)                                                  DBC271
      XO=X                                                              DBC272
      YO=Y                                                              DBC273
   16 RETURN                                                            DBC274
      END                                                               DBC275
```

```
C      THE FULL [illegible] JOB CONTROL [illegible] C [illegible]
C      THE MODEL OF THE OHIO STATE UNIVERSITY [illegible] 370/1[illegible] COMPUTER
C      THEY [illegible] BY [illegible] IT BE APPLICABLE AT ANOTHER INSTALLATION

// (4[illegible]00,5000),CLASS= ,REGION=[illegible]K,TYPRUN=SETUP           [illegible]
//[illegible]STEP EXEC PROC=FORTRAN[illegible]G,PARM.C[illegible]P='MAP',TIME.C[illegible]P=(1,15)
//C[illegible]P.SYSPRINT DD SYSOUT=A                                           [illegible]
//C[illegible]P.SYSIN DD *                                                     [illegible]

C      INSERT PROGRAM DECK HERE

/*
//S[illegible]E EXEC PROC=[illegible]FORT,PARM.LKED='XREF',TIME.LKED=(1,[illegible]),   *  [illegible]
//                 REGION.GO=630K,TIME.GO=(2,45)
//LKED.SYSLIN DD DSNAME=*.USER.C[illegible]P.SYSLIN,DISP=(OLD,DELETE)            [illegible]
//GO.FT06F001 DD SYSOUT=A,DCB=(LRECL=132,RECFM=F[illegible],BLKSIZE=5[illegible])  [illegible]
//GO.FT05F002 DD UNIT=2400,DISP=(OLD,KEEP),LABEL=(7,SL),VOL=(PRIVATE,
//                 RETAIN,SER=SW[illegible]T4),DCB=(RECFM=F[illegible],LRECL=[illegible], BLKSIZE=800),
//                 DSN=SW[illegible]TAPE
//GO.FT07F001 DD SYSOUT=B                                                      [illegible]
//GO.FT04F001 DD SYSOUT=A,DCB=(RECFM=F[illegible]A,LRECL=121,BLKSIZE=[illegible]5)  [illegible]
//GO.SYSIN DD *                                                                [illegible]

C      INSERT DATA CARDS HERE

/*
//
```

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The Ohio State University Version of the Stanford Streamflow Simulation Model

PART III —
USER'S MANUAL
AUGUST 1972

By
Vincent T. Ricca
Associate Professor
of Civil Engineering

Office of
Water Resources Research
United States Department
of the Interior

PROJECTS
B-005-OHIO
B-019-OHIO

State of Ohio
Water Resources Center
Ohio State University

THE OHIO STATE UNIVERSITY VERSION

of the

STANFORD STREAMFLOW SIMULATION MODEL

PART III - USER'S MANUAL

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THE OHIO STATE UNIVERSITY

Columbus, Ohio 43210

OFFICE OF WATER RESOURCES RESEARCH
U.S. Department of the Interior
Matching Grants B-005-OHIO, B-019-OHIO

August 1972

THE OHIO STATE UNIVERSITY VERSION

of the

STANFORD STREAMFLOW SIMULATION MODEL

PART III - USER'S MANUAL

ABSTRACT

Report Parts I & II of this project presented the technical aspects and computer program for the Ohio State University Version of the Stanford Streamflow Simulation Model.

The purpose of this report is to give the potential user of this model a working understanding of the model so that he can use it efficiently and effectively as a tool in hydrologic investigations.

KEY WORDS

Descriptors: Simulation/ Hydrologic Models/ Computer Models/ Streamflow Forecasting/ Evapotranspiration/ Hydrograph Analysis/ Sedimentary Basins/ Snowmelt/ Time of Concentration/ Small Watersheds/ Agricultural Watersheds.

MATCHING GRANT

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The Ohio State University
Columbus, Ohio

HYDROLOGIC INVESTIGATIONS OF SMALL WATERSHEDS IN OHIO

Research With the Stanford Streamflow Simulation Model

1968-1972

PROJECT PERSONNEL

Faculty

Name	Project Position	Department
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TABLE OF CONTENTS

PREFACE

The Ohio State University Version Of The Stanford Streamflow Simulation Model

For convenience of reading and handling, ease of extending or updating, and to suit the reader's particular interest, the publication of the material associated with this model will be reported in three separate volumes.

The volume titles and a brief account of their content are:

The Ohio State University Version of the Stanford Streamflow Simulation Model:

Part I -- Technical Aspects:

A detailed analytical and descriptive presentation of the basic model with discussions on the input and output options, modifications made, test applications, performance evaluation, and developmental topics for future research.

Part II -- The Computer Program:

Definition of program variables (386) and listing of the program statements (1881).

Part III -- User's Manual:

A working understanding of the model so that the potential user can use it efficiently and effectively as a tool in hydrologic investigation.

The technical details in Part I are needed if one wishes to study the basic operation of the model, in particular, if modifications or additions are planned. For the practicing engineer or researcher Parts II and III will suffice for successful running of the model.

The author would appreciate receiving comments concerning both applications of the model and modifications to its structure. Feedback of this nature would be useful for compiling data on the ranges of the initializing parameters with eventual inclusion in updated versions of the User's Manual.

ACKNOWLEDGEMENTS

The work performed in this report has been an interdisciplinary research effort involving faculty, students, and researchers from two branches of U.S. Department of Agriculture.

The supporting material for this manual was compiled from six Master of Science theses (Balk, 1968; Briggs, 1969, Owen, 1970; Mease, 1970; Valentine, 1970; and Warns, 1971) from the Department of Civil Engineering, The Ohio State University.

A major portion of this report was taken directly from a Master of Science thesis written by J. C. Warns, a graduate research student and advisee of Dr. V. T. Ricca.

This manual was written as a portion of a research project, Hydrologic Investigations of Small Watersheds in Ohio, administered by Dr. E. Paul Taiganides, Project Director, Department of Agricultural Engineering, The Ohio State University.

This research was aided by faculty colleagues: Drs. E. P. Taiganides, G.O. Schwab, and M. Y. Hamdy, Professors of Agricultural Engineering, and Dr. G. P. Hanna who at the time served as Director of the Water Resources Center, The Ohio State University. Their counsel and service on thesis reading committees was most helpful.

Many thanks are given to staff of the North Appalachian Experimental Watershed, Coshocton, Ohio, for their encouragement, cooperation, and inexhaustible efforts to supply test data. Mr. L. L. Harrold, Officer-in-Charge and Adjunct Professor of Agricultural Engineering was an inspiration to the students and member of their theses reading committee. Mr. J L. McGuinness, Statistican, supplied much of the test data and assisted in the analysis and interpretation of the modeling results. Dr. W. Edwards, Soil Physicist, freely shared his knowledge of the test watershed soils. In the earlier stages, Mssrs. C.R. Amerman, Watershed Engineer, and J. B. Urban, Geologist, were instrumental in initiating the study.

Gratitude is expressed to Mr. H.N. Holton and his staff of the USDA Hydrograph Laboratory in Beltsville, Maryland. They assisted in determining some of the modeling parameters and supplied their reduced data on the test watersheds. Correspondence and meetings with this group provided much guidance during our endeavors.

Example values for the various parameters compiled from research results were furnished by various researchers working with the model. Acknowledgement of these sources are given within the report.

Of course this entire project could not have been possible if it were not for the cooperation of Professors N.H. Crawford and R.K. Linsley, originators of the model and Dr. L.D. James, who unselfishly gave us his translated version of the model and provided guidance and encouragement throughout this project.

The consultation provided by the staff of The Ohio State University Numerical Computations Laboratory was indispensable during the computer program checkout.

Financial support for this project came from several sources The Office of Water Resources Research; U.S. Department of the Interior; Matching Fund Grants B-005-OHIO and B-019-OHIO; The Ohio State University Departments of Civil Engineering and Agricultural Engineering; and Graduate Student Traineeships, Federal Water Pollution Control Administration, U.S. Department of the Interior.

Special thanks are due to the staff of The Ohio State University Water Resources Center, Dr. K. S. Shumate, Director, for their administrative assistance.

Columbus, Ohio

Vincent T. Ricca
Principal Investigator

INTRODUCTION

The technical aspects of and the evaluation of the Ohio State University Version of the Stanford Streamflow Simulation model have been discussed in a separate, Part - I, report.

The actual computer program of the model is presented in another, Part - II, report.

This manual, Part - III, is the concluding section of the report. It is designed to accompany the computer program and was written with the following objectives in mind:

i. Quickly give the user a working understanding of the model, and

ii. Show him how to efficiently and effectively use the model as a tool in hydrologic investigations.

To implement these objectives, an approach along these lines was taken and reported herein to produce this manual:

i. The model is discussed in general terms so that the investigator can judge if the model might be an aid in solving his particular problems. To assist in this discussion, various potential applications are presented in addition to a survey of some projects which have effectively used the model. Further, comments on the limitations of the model are noted so that a more realistic evaluation of the ulility of the model can be made.

ii. A review of the absolute minimum requirements for using the model is presented so that the potential user can ascertain if he has the necessary data, financial and manpower resources, and computer facilities.

iii. A detailed running of the model is discussed including definitions of input parameter values, modification of these input parameters for refining results, and description and explanation of the output.

USES AND LIMITATIONS OF THE MODEL

Uses

It is impossible to conceive of every possible use of the Stanford Watershed Model. However, some of its applications should be mentioned so that the reader can get a perspective of the utility of the model.

The hydrologist, with the aid of the model, can rapidly analyze the detailed and complex runoff phenomenon to an extent never before possible. In the past, the hydrologist, limited by time and labor, could use only a fraction of a watershed's characteristic data in his analysis. Further, methods used were usually oversimplified and required much judgment and experience in selecting appropriate coefficients. For example, the Rational Formula assumes that rainfall intensity is constant and uniform over the entire watershed. The Rational Formula also makes the broad assumption that the frequency of large floods corresponds with the frequency of the rainfall producing them (25, p. 75). These things inherently lead to a conservative design approach and an increase in project costs. Considering the large expenses involved in providing drainage facilities, it is clear that more comprehensive computerized analysis should be used.

The Stanford Watershed Model, because its parameters reflect particular hydrologic characteristics, offers the hydrologist a way of predicting how a watershed responds to a large variety of stimuli. For example, using the model, a hydrologist could predict changes in streamflow caused by urbanization, channel improvements, or tributary area changes. Also, the model can be used to study the hydrologic effects of physiographical and climatological changes in watershed due to forest fires, soil conservation techniques, and various land use practices. Generalizing on the above discussion, one of the most useful features of the model is the way the parameters, which describe the watershed characteristics, can be varied to gain a better understanding of the effects of environmental changes.

Another important application of the model is the extension of short duration streamflow records from long duration precipitation records. Further, in addition to the model's numerous applications in the analysis of water resource systems, it may be used in the teaching of hydrology or simply to uncover information gaps in watershed studies.

Research at some of the universities across the country has seen the model applied in hydrologic study of the following: small agricultural watersheds (2, 4, 37), sedimentation (27), rainfall augmentation (23), floodwater retarding structures (26), prediction of flood peaks (6), runoff coefficients (25), stratified geologic basin (28), and snowmelt runoff in Ohio (24).

Limitations

The Stanford Watershed Model will not solve all the hydrologist's problems; however, it is a significant development in hydrologic research and, if used with a knowledge of its inherent limitations, can produce meaningful results.

First, it must be realized that models are born in the mind of the originator; thus, they are limited by the designer's background, his available information, and his ability to extend qualitative knowledge about the hydrologic cycle into quantitative terms.

Simulation models, like the Stanford Watershed Model, which describe the watershed as a collection of mathematical expressions and parameters, are further inhibited by the actual physical limitations involved in acquiring the complex types of input data. Therefore, models can only include the significant elements which have readily accessible data.

A fundamental limitation of the Stanford Watershed Model is its dependence upon the "lumped" system concept. With this concept, regardless of the number of components used in the model, the parameters represent an average effect of a particular component over the entire watershed (11, p. 17). For example, the model only considers the magnitude of impervious area within a watershed and not the distribution. Also, the "lumped" system of parameter calculation does not, in all cases, reflect complex interactions among all components of the watershed system.

Models are further limited by the possibility that they may be calibrated with unrepresentative data. Simulation accuracy is entirely dependent upon the accuracy of the data. It is useless to adjust parameters without reliable data.

The cost of computer time may also limit the use of the model. Adjusting input parameters to achieve better results may take a dozen or more runs. With each run requiring about three minutes and the cost of computer time being approximately \$1000/hour, this represents an initial investment, in computer time alone, of perhaps \$1000.

Concluding Comments

Finally, it must be realized that the model does not function as a "black box". It must be used intelligently and carefully as an aid in streamflow study. The model only augments analysis; it cannot substitute for sound engineering judgment. Further, because of the time, effort, and expense involved, the model is limited to projects that warrant a more detailed analysis.

BASIC REQUIREMENTS

The Stanford Watershed Model is a lengthy and detailed digital computer program. The practicing engineer may not always have the background or facilities necessary to use the model effectively. The listing below presents the basic requirements of hardware, data, and background information that are absolutely essential for running the model and achieving meaningful results. These items will be discussed in detail in the body of this chapter.

1. Streamflow Simulation Computer Program
2. High Speed Digital Computer
3. Plotter Facilities
4. Data
5. Knowledge of Fortran IV
6. Knowledge of Hydrologic Concepts
7. Computer Consultant
8. Time

1. Streamflow Simulation Computer Program

A copy of the program, which is approximately 1900 lines long, is given in Part II - The Computer Program; a copy of the card deck is on file in the Hydrology Laboratory of the Department of Civil Engineering, The Ohio State University. Deck copies can be furnished at a nominal reproducing charge.

2. High Speed Digital Computer

The computer must be able to process Fortran IV G Level computer language and it must have a core storage capacity which ranges from approximately 300 K bytes, if no options are called, to approximately 630 K bytes if all the options are exercised. Note, however, that the snowmelt option accounts for nearly all of this increase. Also, the program presently requires a nine-track standard label tape. However, with minor changes, the program can use all card input. At the Ohio State University, an I.B.M. 370/165 computer is presently being used.

3. Plotter Facilities

The user must compare the simulated streamflow hydrographs against the recorded streamflow hydrographs in order to evaluate the accuracy of the simulation and to judge what action must be taken to improve simulation. Although the vast quantities of simulation data are outputted in tabular form and can be plotted by hand, this is an extremely tedious task. Instead, past researchers have programmed options into the model whereby a computer plotting facility can be used to graph this data (see Logarithmic, Arithmetic, and Selected Storm Plot Options). At The Ohio State University, either an I.B.M. 1130 computer or an I.B.M. 1620 computer is used to drive an I.B.M. 1627 plotter.

4. Data

The Stanford Watershed Model requires a great deal of data, most of which can be acquired without too much difficulty as discussed in Chapter IV. However, because of carry-over effects that exist from year to year in the calculations involving hydrologic quantities, at least three and preferably five, years of data are required for the model to adjust itself and reach an equilibrium in its soil moisture balance.

5. Knowledge of Fortran IV Computer Language

The Stanford Watershed Model IV, O.S.U. Version, is written in Fortran IV G Level computer language. Although every effort will be made in this manual to minimize programming details, a working knowledge of Fortran IV will be extremely helpful.

6. Knowledge of Hydrologic Concepts

The user must have a sound background in hydrology. He must understand hydrologic terms and the hydrologic cycle to effectively modify parameters and improve streamflow simulation.

7. Computer Consultant

In addition to the hardware requirements, the user must either be a competent programmer or have the counsel of a computer consultant. Since, each computer installation is unique, Job Control Language cards, as given in this report will probably not operate at a computer system of another installation or even at the same facility after a period of time. A competent computer consultant will be invaluable in adapting the model to a different facility, in updating control cards for the existing system, and in debugging problems in program execution.

8. Time

The Stanford Watershed Model does not provide what one might consider a quick or easy method of analyzing streamflow. The time requirements, particularly for the initial running of the model with no prior experience could be lengthy, perhaps several days. Therefore, one will not want to use the model for every investigation until experience is gained. However, where the size or cost of a project make a detailed analysis feasible, the Stanford Watershed Model is one of the best tools available.

MODEL OPERATION

Introduction

This chapter discusses the input and output of the model along with the modification of the parameters for better simulation. The chapter is divided into three sections.

First, the Required Input (input absolutely essential for running the model) and the Basic Output (output if no additional options are called) are discussed using this format:

1. The sequence of this discussion will follow that shown under Required Input of Figure 1 . The circled numbers ((1)) indicate the positions of the data sets in the input card deck or on the tape.
2. Each set of data is introduced by a Read Statement which lists the variables and notes the actual computer format.
3. An example of a typical input card set, in the correct sequence, is shown.
4. Each input variable (all variables are blocked $\boxed{\text{VARIABLE}}$) is discussed including its definition, determination of its value, some actual example values, and possible sources of data.
5. Following a discussion of all the required input, an example of the basic output is given and explained.

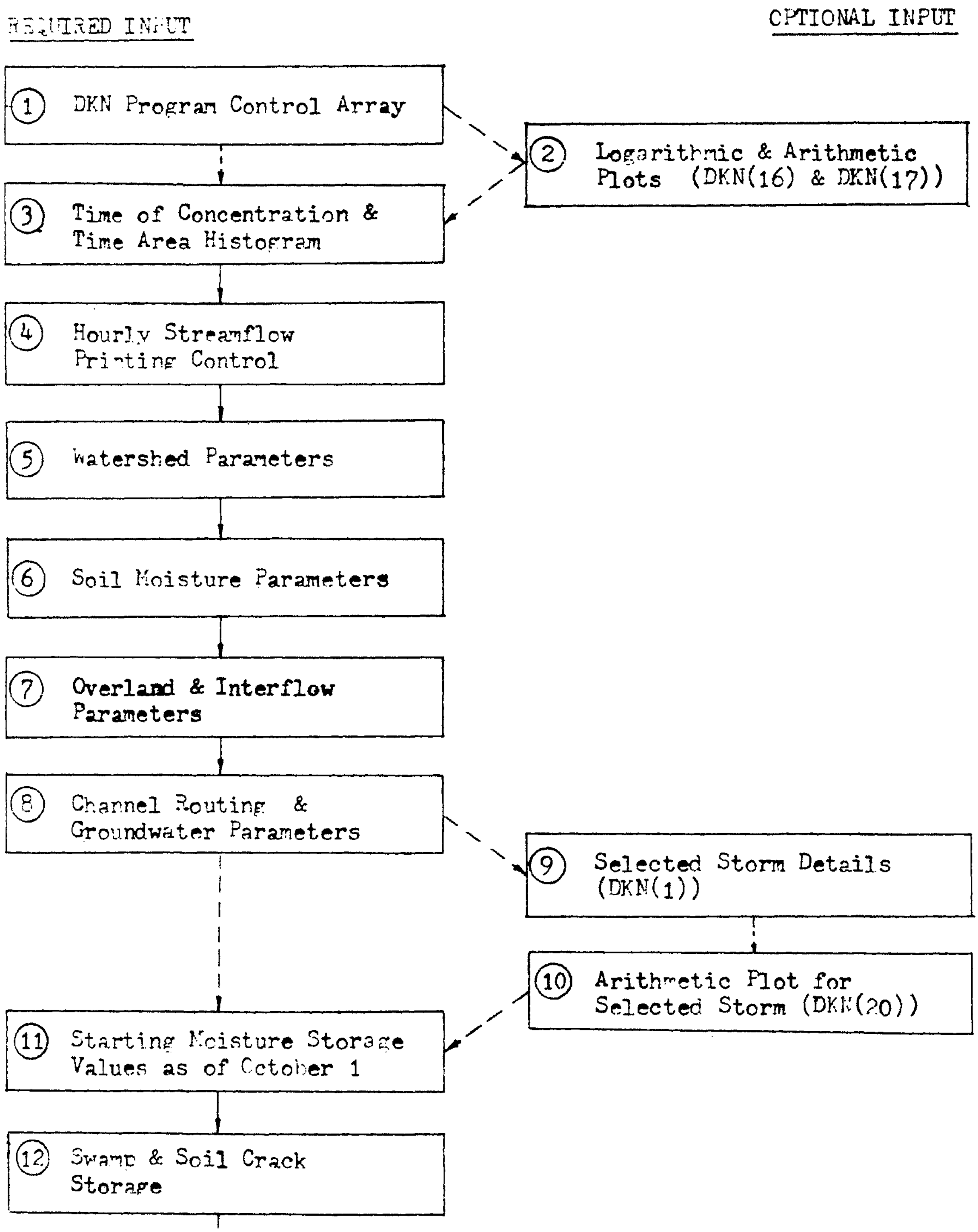
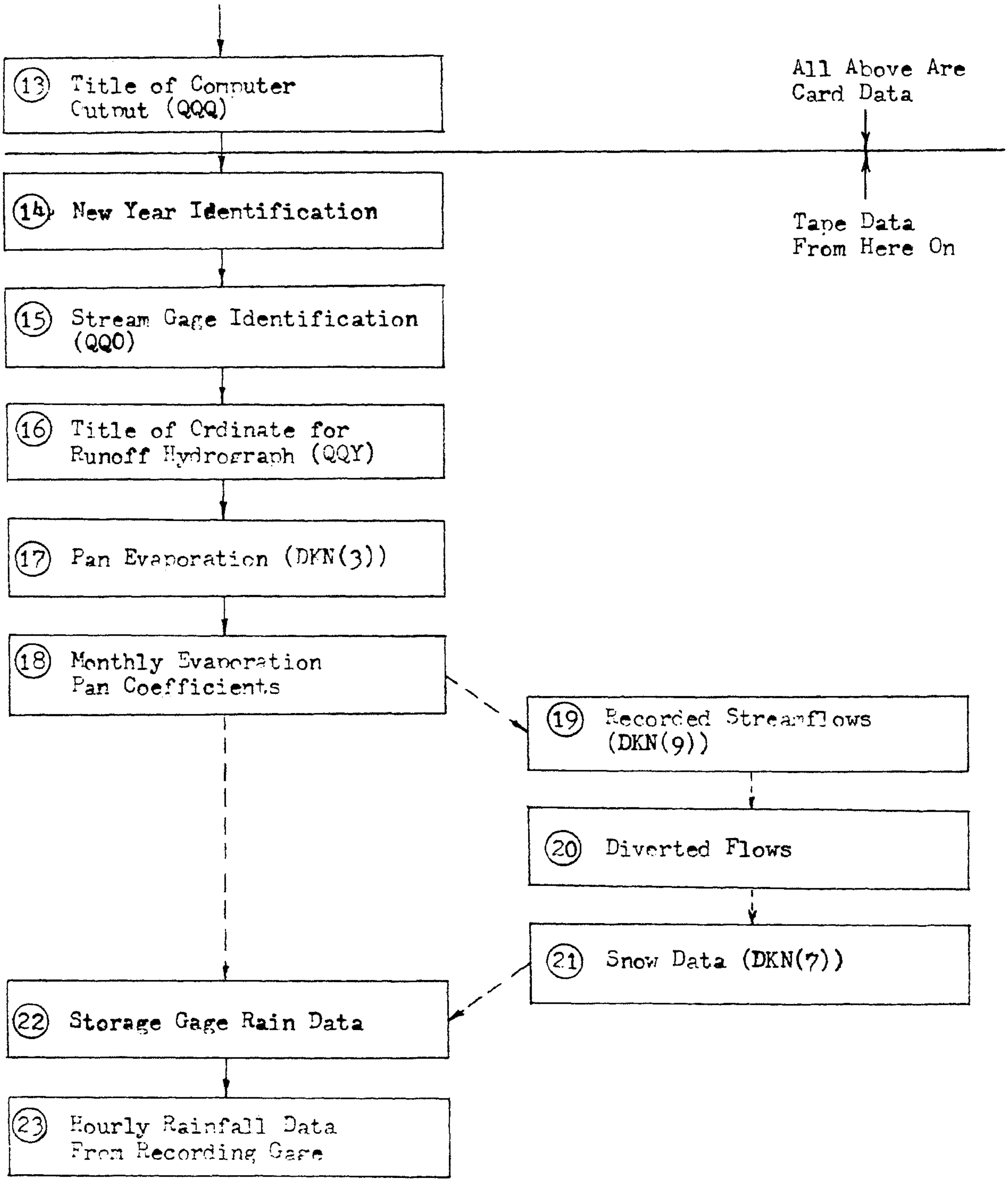


FIGURE 1. DATA SEQUENCE

Figure 1.
(cont.)



Second, the Optional Input and Output is discussed using a similar format as above:

1. The sequence of this discussion follows the numerical order of the DKN options (DKN(1) through DKN(20)). The circled numbers (1) indicate the positions of the data sets, if required, in the input card deck or on the tape.
2. The function of the option is explained.
3. If additional input is required, it is introduced with a Read Statement which lists the variables and notes the actual computer format.
4. An example of a typical input card set, in the correct sequence, is shown.
5. Each input variable ($\boxed{\text{VARIABLE}}$), is discussed including its definition, determination of its value, some actual example values, and possible sources of data.
6. Any additional output provided for by the option is explained.

Finally, under Modification of Parameters, guidelines are given for improving simulation results.

As mentioned above, for some of the variables, actual example values are cited. These values come from research work with the model on several different watersheds. Briggs (4) used Little Mill Creek near Coshocton, Ohio, a small unglaciated agricultural watershed in the Allegheny Plateau. Clarke (6) used Cave Creek, a small watershed, used predominantly for pasturing, near Lexington, Kentucky. Drooker (8) used the Hubbard Brook Watershed, a small glaciated watershed covered with secondary forest growth, located in the White Mountains of the Appalachian Mountain Range near West Thornton, New Hampshire. Ligon, Law, and Higgins (20) used the Clemson Research Watershed, situated on the Clemson University in northwestern South Carolina, covered by a combination of open fields and wooded areas. Additional sample values that were presented in a report by Crawford(12') on the application of digital simulation to urban hydrology are tabulated in the appendix.

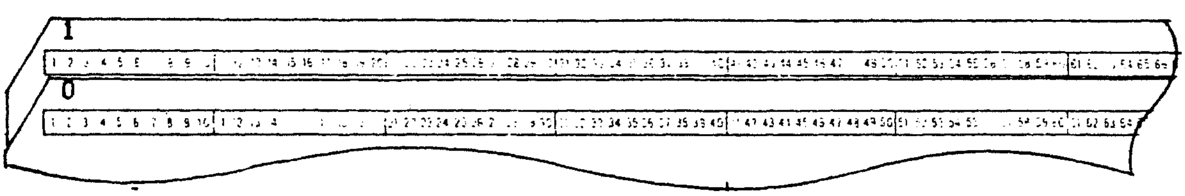
Required Input

This discussion presents all input data that are absolutely necessary for running the model.

1 DKN - Control Array

Read: One value (1 or 0) from each of twenty cards (corresponding to the twenty DKN options) with an I2 Format. The path followed by each DKN option (see Optional Input and Output p. 60) is controlled either by a "1" or a "0" in the option input data.

Example of Input - Shown below are two typical input cards for the DKN - Control Array.



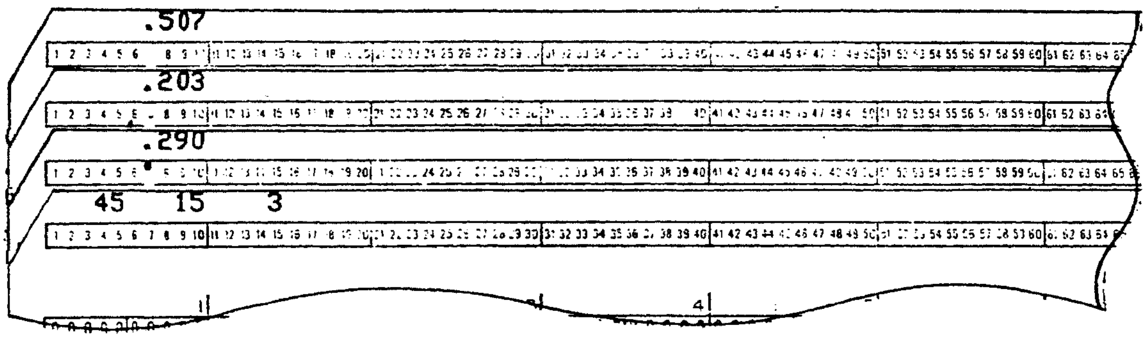
3 Time of Concentration and Time Area Histogram

Time of Concentration

Read: TCONC, TINC, Z from one card with a 3I5 Format.

Read: One value of C from each of Z cards with a F10.3 Format.

Example of Input - Shown below is an example of the card input for the Time of Concentration and the Time Area Histogram data.



$\boxed{\text{TCONC}}$ - is the time, in minutes, for water originating in the most remote region of the watershed to reach the measuring station.

Determination of TCONC :

The time-of-concentration may be computed by the empirical equation developed by Z. P. Kirpich and presented by Clarke (6, p. 39):

$$Tc = 0.0078 \left\{ \frac{L}{S^{\frac{1}{2}}} \right\}^{0.77}$$

where Tc is the time of concentration in minutes, L is the horizontal length in feet from the most distant point in the basin to the outlet, and S is the slope between these points. Note, that since much of the data upon which this equation is based was taken from watersheds larger than 15 acres (Tc greater than 2 minutes), its accuracy on very small watersheds is questionable

$\boxed{\text{TINC}}$ - is the selected routing interval in minutes.

Determination of TINC:

1. TINC must be divisible into TCONC (time of concentration) such that a whole number of time-area histogram elements (Z) can be obtained. TCONC may have to be rounded to a convenient value to achieve this.

2. TINC must yield a whole number when divided into 60 minutes. Therefore, TINC can assume the following values: 1, 2, 3, 4, 5, 6, 10, 12, 15, 30, and 60 minutes.

Valentine (37, p. 10) gives an example to illustrate these two limitations. A watershed with a time of concentration of 15 minutes has the following possible combinations:

TINC	Z	NINC
15	1	4
5	3	12
3	5	20
1	15	60

where NINC is the number of multiples of the routing interval per hour. Generally, because of excessive computer time requirements, increments smaller than 5 minutes should not be used. Also, for rough approximations or large watersheds, using larger time increments will reduce costs.

Time Area Histogram

$\boxed{\text{Z}}$ - is the number of elements in the current time-area histogram. (See below, Determination of Z and C.)

$\boxed{\text{C}}$ - is the time-area histogram ordinate value.

Determination of Z and C:

Using Balk's work (2, p. 62) as a guide, the following outline is presented for determining Z and C in the time area histogram.

1. Applying the Kirpich formula, as discussed previously under TCONC, or some other reliable time of concentration formula, and using a suitable topographic map, compute the flow time from various locations along the main channel and tributaries of the basin and note these times on the topographic map (see Figure 2a).

2. By interpolating between the noted times, draw lines of equal flow times (isochrones). See Figure 2b , where 15 minute isochrones are drawn.

3. From measurements of the area bounded by each pair of isochrones, compute the fraction of the total watershed within each pair. See Figure 2b for sample computations and corresponding values for Z and C.

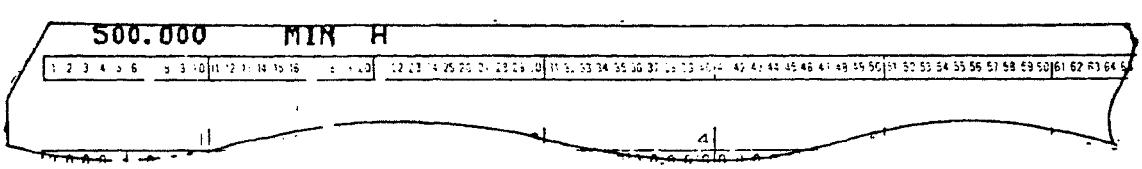
Sources of Topographic Maps:

i. Geological Survey, Map Information Office
ii. State Highway Departments
iii. City or County Engineer's Office

4 Hourly Streamflow Printing Control

Read: One value of MINH from one card with a F10.3 Format.

Example of Input - Shown below is a typical example of an input card for MINH data.



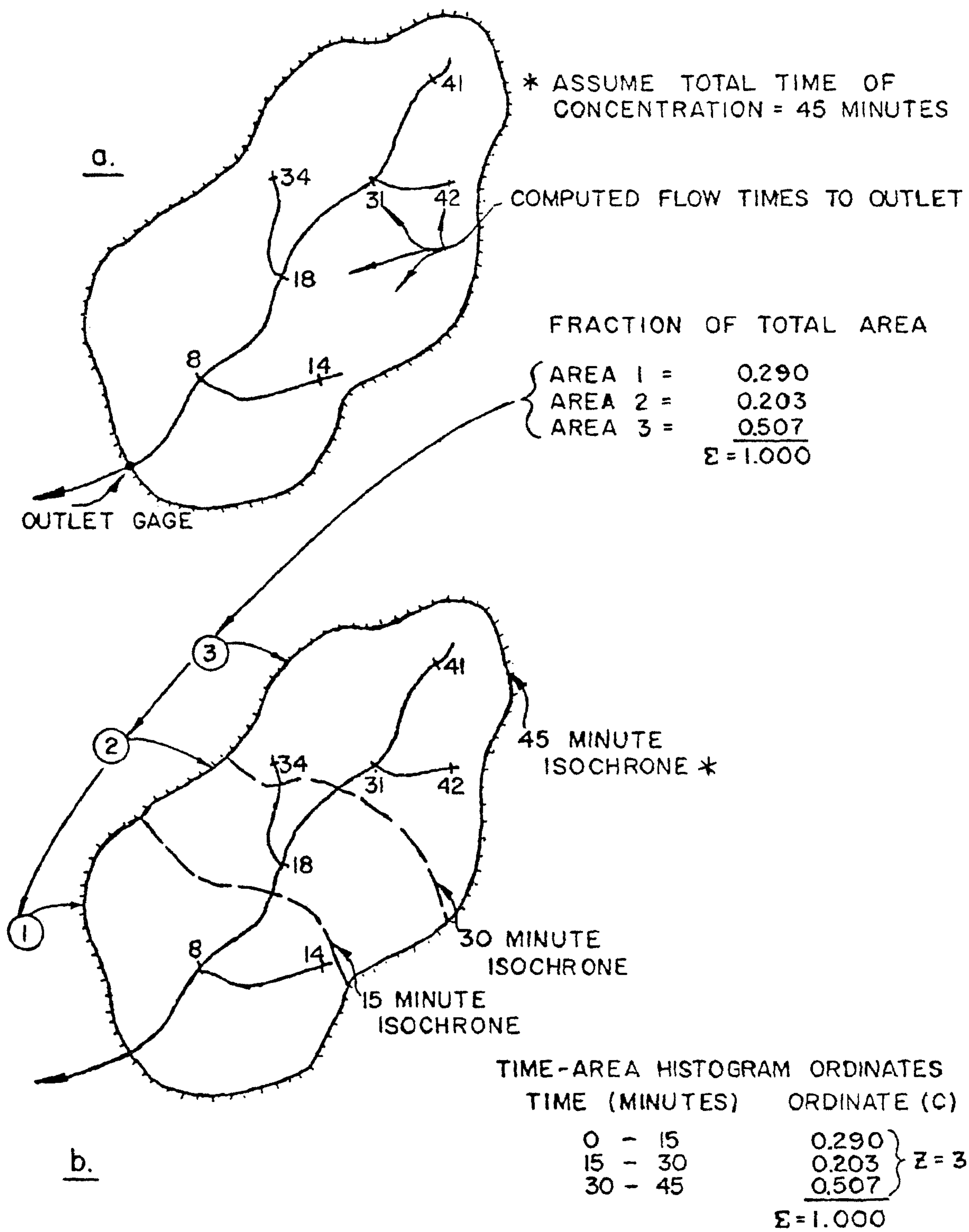


FIGURE 2 - DEVELOPMENT OF TIME-AREA HISTOGRAM

(After Balk (2))

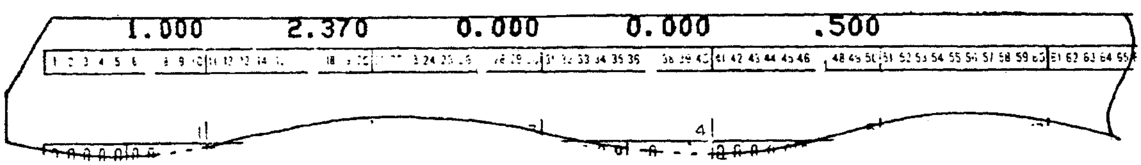
$\boxed{\text{MINH}}$ - Hourly flows are printed if flow exceeds this value; therefore, this value will vary depending on the purpose of the simulation (cfs).

Output - If MINH is exceeded. For the date that MINH was exceeded, synthesized hourly flow rates, in cubic feet per second, are given for the A.M. and P.M. followed by the daily average flow rate. Also, the maximum flow rate and time of occurrence is given.

5 Watershed Parameters

Read: K1, AREA, A, ETL, EMIN from one card with a 5F10.3 Format.

Example of Input - Shown below is a typical input card for the Watershed Parameter data.



$\boxed{\text{K1}}$ - is the long term ratio of average rainfall over the basin to the average rainfall over the study watersheds. K1 acts as an adjustment factor if the precipitation of the watershed being used in the simulation is different from the pattern at the recording gage.

Determination of K1:

1. K1 may be determined by any precipitation weighting technique such as arithmetic averaging, Thiessen method, or isohyetal method.

2. K1 can be approximated on the basis of experience. For example, if it was thought that the study watershed received one-half the precipitation recorded at the gage, K1 would be set equal to 0.5.

Sources of Isohyetal Maps:

i. Regional Office of the United States Weather Bureau
ii. Corps of Engineers

Sources of Precipitation - See Hourly Rainfall Data From Recording Gage (P1).

AREA - is the watershed drainage area in square miles.

Determination of AREA:

Topographic maps and aerial photographs can be used to establish watershed boundaries. The watershed area can then be determined by planimetering the topographic map. Sewered areas, which drain to adjacent watersheds, are not included in this area.

Sources of Topographic Maps - See Time Area Histogram (Z and C)

Sources of Aerial Photographs:

i. Department of Agriculture
ii. Forest Service
iii. Bureau of Reclamation
iv. Department of Interior
v. Soil Conservation Service
vi. Corps of Engineers
vii. State Highway Departments
viii. Geological Survey

A - is the impervious fraction of the watershed surface. This fraction only includes impervious area (exposed rocks, roads, buildings, etc.) that drain directly into the stream channel; that is, it excludes impervious areas from which the runoff must cross a pervious area before reaching the channel (15, p. 225).

Notes on Use :

1. The relation between runoff and urbanization is more sensitive to A than to other parameters (14, p. 73).

2. Increasing impervious area amplifies flood peaks and runoff volumes or it may extend or shift the flooding season from spring to the summer months (6, p. 76).

Determination of A :

1. A is usually zero for rural or undeveloped areas unless there are large areas of exposed rock.

2. It may be measured directly from aerial photographs.

3. Personal reconnaissance of the area has been found helpful.

4. Figure 3 , to be used when considering typical urbanized watersheds, relates effective impervious area to the total impervious area.

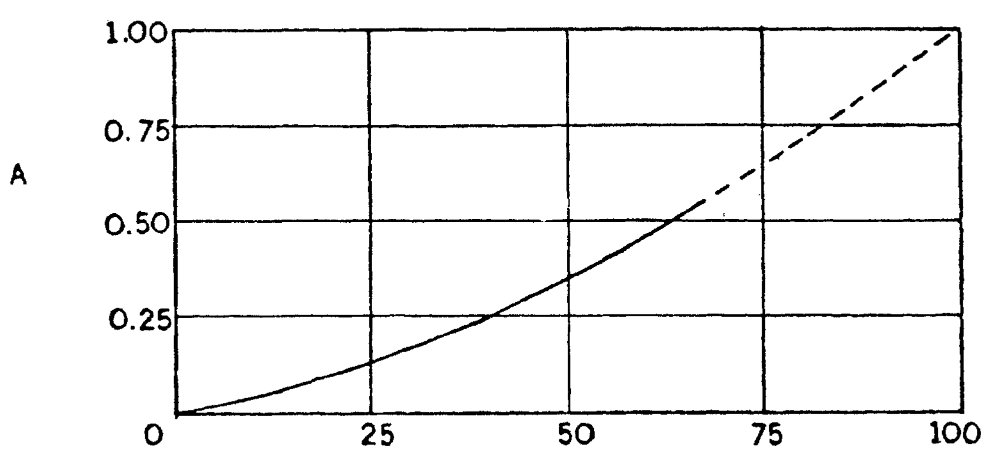


FIGURE 3. TOTAL IMPERVIOUS AREA (Percent)

(after Crawford et al. (7))

5. Sarma, Delleur, and Rao, (30, p. 77) present a method of obtaining an estimate of the percentage of impervious area in a watershed. In this method, the impervious area within several representative "sample-areas", determined from aerial photographs, is used in a weighted average computation to estimate the total impervious area.

Sources of Topographic Maps - See Time Area Histogram (Z and C)

Sources of Aerial Photographs - See Watershed Parameters (AREA)

$\boxed{\text{ETL}}$ - is an estimate of the stream and lake surface area as a fraction of the total watershed area from which evaporation should occur at the potential rate (7, p. 69).

Determination of ETL:

1. ETL may be estimated from topographic maps or aerial photographs.

2. The water surface area of a stream can be calculated by a formula taken from Linsley (22, p. 252):

$$A = \frac{BL}{2}$$

A = Water surface area of a stream
B = Channel width at the outlet
L = Stream length

Sources of Topographic Maps - See Time Area Histogram (Z and C)

Sources of Aerial Photographs - See Watershed Parameters (AREA)

EMIN - is the minimum value of EN, a factor varying infiltration by season. According to Briggs (4, p. 19), and increase of EMIN causes yield volumes to drop and winter peaks to be reduced.

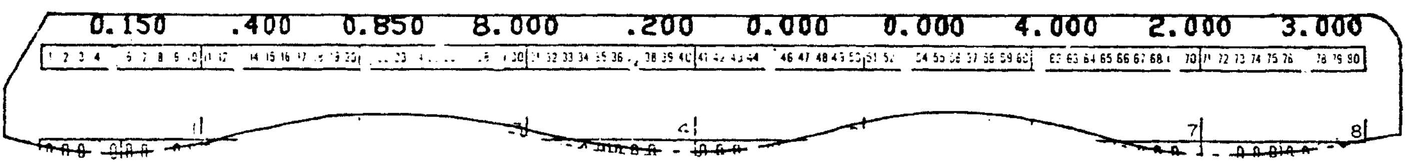
Determiniation of EMIN:

1. It is best established by trial and adjustment.
2. Briggs (4, p. 19) gives a range of between 0.1 and 1.0 for EMIN.
3. Briggs (4) used a value of 0.5 for Little Mill Creek.
4. See Modification of Parameters for more discussion.

6 Soil Moisture Parameters

Read: EPXM, CX, EDF, LZSN, K3, K24L, K24EL, EF, CB, CY from one card with a 10F 8.3 Format.

Example of Input - Shown below is a typical input card for the Soil Moisture Parameter data.



EPXM - is the maximum interception rate for a dry watershed in inches per hour. The amount of interception is controlled by the type and density of vegetative cover and the volume currently in interception storage. The model uses EPXM for storage of all incoming moisture to the watershed until a preassigned value is obtained; moisture exceeding this becomes available for overland flow.

Determination of EPXM:

1. Table 1. as presented by Crawford and Linsley (7, p. 66), presents a range of values for EPXM.

TABLE 1.

Watershed Cover	EPXM
Grassland	0.10
Moderate forest cover	0.15
Heavy forest cover	0.2

2. Todd (32, p. 70) presents interception percentages of various forest and crop types. His table may be helpful in determining EPXM.

3. Briggs (4) used a value of 0.15 for Little Mill Creek.

4. Clarke (6) found a value of 0.10 for Cave Creek.

5. Ligon, Law, and Higgins (20) used a value of 0.20 for the Clemson Research Watershed.

6. Drooker (8) chose a value of 0.1 for Hubbard Brook.

7. See Modification of Parameters for further discussion.

$\boxed{\text{CX}}$ - is an index for estimating the capacity of the soil surface to store water in interception and depression storage. It does not have much effect on the water balance and is used mainly as a fine-tuning adjustment. Note, however, when varying this parameter, that urban watersheds generally have much less depression storage volume than do agricultural lands.

Determination of CX:

1. CX is best established by trial and adjustment

2. According to Clarke's (6, p. 71) guidelines, initial values of CX may range from 0.10 to 1.65.

3. Clarke (6) found a value of 0.9 for Cave Creek.

4. Balk (2) chose a value of 0.7 for Little Mill Creek.

5. Ligon, Law, and Higgins (20) used a value of 3.0 for the Clemson Research Watershed.

6. Drooker (8) employed a value of 0.5 for Hubbard Brook.

7. See Modification of Parameters for further discussion.

EDF - is an index for estimating soil-surface moisture storage capacity. It represents the additional moisture - storage capacity available during warmer months caused by summer vegetation. When EDF is increased, there is more water held on or immediately below the soil surface to be evaporated, hence less water contributes to runoff (4, p. 14).

Determination of EDF:

1. EDF is best established by trial and adjustment.

2. According to Clarke's (6, p. 71) guidelines, initial values of EDF may range from 2.00 to 0.45.

3. Balk (2) chose a value of 1.0 for Little Mill Creek.

4. Clarke (6) used a value of 1.165 for Cave Creek.

5. Ligon, Law, and Higgins (20) found a value of 1.75 for the Clemson Research Watershed.

6. Drooker (8) employed a value of 0.5 for Hubbard Brook.

7. A knowledge of the soil type will be helpful in determining EDF. For example, sandy soils readily give up moisture

to vegetation and thus will provide an increased storage capacity.

8. See Modification of Parameters for further discussion.

Sources of Soil Data:

i. Soil Conservation Service (SCS National Engineering Handbook)
ii. The Water Encyclopedia (32, p. 72)
iii. County Soil Survey Reports
iv. State Departments of Natural Resources, Division of Lands and Soil

LZSN - is a soil profile moisture storage index, in inches, which approximately equals the volume of water that may be stored in the soil between the ground surface and watertable, but which will also drain freely by gravity (2, p. 69). Further, it is a major runoff volume parameter which is used to control rates of infiltration, evapotranspiration, and percolation of groundwater. Decreasing LZSN significantly increases yields and causes a moderate increase in interflow and groundwater flow.

Determination of LZSN:

1. LZSN is best established by trial and adjustment.

2. Clarke (6, p. 72) suggests that LZSN is approximately equal to 20 percent of the soil depth (or the ratio of the volume of water that will drain freely from most soils to the volume of soil solids). Using this criteria, he established a range of between 12.0 and 2.0 for Kentucky watersheds.

3. Guidelines by Crawford and Linsley (7, p. 76) for estimating initial values of LZSN are as follows:

For Seasonal Rainfall

$$LZSN = 4 + \frac{1}{2} \text{ (Mean Annual Rainfall)}$$

For Uniform Rainfall

$$(LZSN = 4 + 1/8 \text{ (Mean Annual Rainfall)}$$

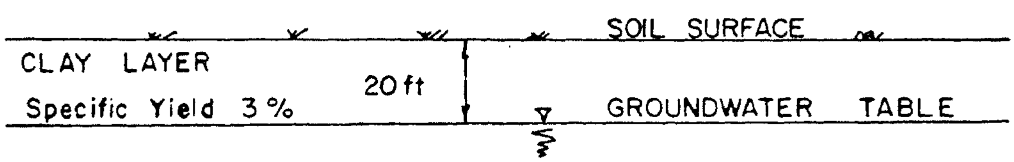
4. Porosity and specific yield information on the soil types will be helpful in determining LZSN (see Table 2.).

TABLE 2.

Approximate Average Porosity, Specific Yield and Permeability of Various Materials (After Linsley et al. (21))

Material	Porosity %	Specific Yield %	Permeability gpd/sq ft
Clay	45	3	1
Sand	35	25	800
Gravel	25	22	5000
Gravel and Sand	20	16	2000
Sandstone	15	8	900
Dense Limestone and Shale	5	2	1
Quartzite, Granite	1	0.5	0.1

For example, if well logs, boring records, or soil profiles indicate 20 feet of clay (see below), LZSN might be approximated as 20 feet x 12 inches x 0.03 = 7.2 inches.



Sources of Well Logs:

i. Local Offices of the Geological Survey
ii. Local Department of Health

Sources of Boring Records:

i. State Highway Departments

Sources of Soil Data - See Soil Moisture Parameters (EDF)

5. Holtan (9) has published hydrologic capacities of various soils which may be helpful in determining the relative magnitude of this parameter.

Also, LZSN (Soil moisture storage index) and CB (Infiltration index) are interdependent. The combination that produces the best long term groundwater and surface runoff volumes, and short term response in individual storms must be found.

6. Briggs (4) used values ranging from 20. to 12. for Little Mill Creek.

7. Ligon, Law, and Higgins (20) chose a value of 10.0 for the Clemson Research Watershed.

8. Drooker (8) found a value of 4.00 for Hubbard Brook.

9. See Modification of Parameters for further discussion.

$\boxed{\text{K3}}$ - is a soil evaporation parameter which measures the rate of loss through evapotranspiration from lower zone soil moisture.

Determination of K3:

1. Crawford and Linsley (7) suggest K3 values as listed in the first column of Table 3.

TABLE 3.

Watershed Cover	K3	
Open Land	.2	.25
Grassland	.23	↓
Light Forest	.28	↓
Heavy Forest	.3	(.7-.9)

The upper range of values in the second column, are suggested by Hydrocomp International (12), who define K3 as the area covered by forest or deep rooted vegetation as a fraction of the total watershed area. Where the root zone approaches the water table, the uptake of water by roots equals, for practical purposes, the transpiration rate.

2. Aerial photographs will be valuable in determining the watershed cover.

<u>Sources of Aerial Photographs</u> - See Watershed Parameters (AREA)

3. Briggs (4) chose a value of 0.20 for Little Mill Creek.

4. Clarke (6), using various Kentucky watersheds, established a range of between 0.2 and 0.3 for K3.

5. Ligon, Law, and Higgins (20) found a value of 0.32 for the Clemson Research Watershed.

6. Drooker (8) employed a value of 0.8 for Hubbard Brook.

7. See Modification of Parameters for further discussion.

K24L - is a parameter indicating the fraction of moisture lost or diverted from active groundwater storage through subsurface flow across the drainage basin boundary (2). K24L also represents that portion of inflow to groundwater that percolates to deep or inactive groundwater (7).

<u>Determination of K24L</u> :

1. K24L can often be assumed to be zero, since these losses are small compared to rainfall and runoff.

2. K24L may be estimated from observed changes in deep groundwater levels.

Sources of Groundwater Levels:

i. Observation wells
ii. Local municipalities and/or land owners

3. K24L may be approximated by trial.

4. Briggs (4); Clarke (6); Ligon, Law, and Higgins (20); and Drooker (8) all used 0.0 in their studies.

K24EL - According to Clarke (6, p. 44), K24EL is the fraction of moisture lost from groundwater storage through evapotranspiration. Crawford and Linsley (7, p. 43) give K24EL essentially the same meaning, however, they describe it as the fraction of the total watershed area in which evapotranspiration from groundwater storage is assumed to occur at the potential rate.

Determination of K24EL :

1. K24EL is zero unless a significant quantity of vegetation draws from below the water table.
2. Soil Survey Reports, which usually contain information on the vegetation of the area, will be helpful in determining K24EL.
3. Clarke (6), Briggs (4), and Drooker (8) all used 0.0 in their analysis.

Sources of Vegetation Data:

i. Aerial Photographs
ii. County Soil Survey Reports

EF - is a factor relating infiltration rates to evaporation rates to provide a seasonal adjustment and account for more rapid infiltration rate recovery during warmer periods. An increase of EF will increase the infiltration rate in the summer and decrease the summer peaks.

Determination of EF:

1. No methods have been given for estimating an initial value of EF.

2. Balk (2, p. 68) suggests making an initial run with EF = 1.0; then adjust the value of EF as necessary.

3. Briggs (4) chose a value of 4.0 for Little Mill Creek.

4. Clarke (6) found a value of 0.15 for Cave Creek.

5. Ligon, Law, and Higgins (20) used a value of 0.2 for the Clemson Research Watershed.

6. Drooker (8) chose a value of 0.2 for Hubbard Brook.

7. See Modification of Parameters for further discussion.

CB - is an index that controls the rate of infiltration. It is primarily governed by soil permeability and the volume of moisture that may be stored within the soil. An increase of the value of CB has a significant effect in reducing the total yield and increasing interflow and groundwater flow.

Determination of CB:

1. Presently, there are no procedures for estimating initial values of CB.

2. Crawford and Linsley (7, p. 76) suggest a range of between 0.3 and 1.2 for CB.

3. Clarke (6, p. 74) has hypothesized that CB is approximately equal to 20 percent of the soil permeability. Using this, he

found a range of from 1.3 to 0.3 for Kentucky watersheds.

4. A knowledge of the soil type and its permeability will be helpful in determining the relative magnitude of CB (see Table 4.2).

5. Holtan's (10) work, in expressing the infiltration capacity as a function of storage exhaustion and a seepage constant, may also be helpful.

6. Clarke (6) found a value of 0.65 for Cave Creek.

7. Briggs (4) used a value of 0.85 for Little Mill Creek.

8. Ligon, Law, and Higgins (20) chose a value of 3.25 for the Clemson Research Watershed.

9. Drooker (8) found a value of 2.5 for Hubbard Brook.

10. See Modification of Parameters for further discussion.

CY - is an index controlling the time distribution and quantities of moisture entering interflow (6, p. 49). Changes in CY have little affect on yield. An increase in CY will increase the proportion of interflow and reduce the hydrograph peak.

Determination of CY:

1. CY is best established by trial and adjustment.

2. Briggs (4) used a value of 3.0 for Little Mill Creek.

3. Clarke (6) established a range of from 1.0 to 4.5 for various watersheds throughout Kentucky. Also, he noted that this range varies inversely with the depth of the hydrologic activity, which may be estimated as the depth to bedrock, soil layers of restricted permeability, or the water table.

4. Drooker (8) chose a value of 1.0 for Hubbard Brook.

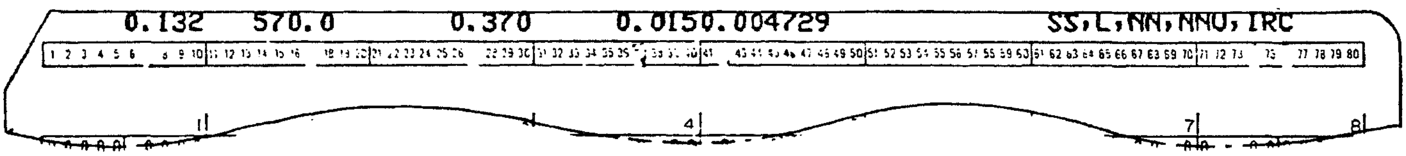
5. Ligon, Law, and Higgins (20) used a value of 0.65 for the Clemson Research Watershed.

6. See Modification of Parameters for further discussion.

(7) Overland and Interflow Parameters

Read: SS, L, NN, NNU, IRC from one card with 4F10.3, F20.18 Format.

Example of Input - Shown below is a typical input card for the Overland and Interflow Parameter data.



SS - is the average ground slope in feet per foot of the overland flow surfaces perpendicular to the channel (6, p. 44). The general land slope has a complex relationship to the surface runoff phenomena arising from its influence on infiltration, soil moisture content, and vegetative growth.

Determination of SS:

1. A method described by Aronovici (1) and discussed by Balk (2, p. 73) consists of overlaying a topographic map of the watershed with a grid system. The slope is determined at each grid intersection by measuring the distance between two contour lines and dividing the contour interval by this distance. The values are then averaged for the entire watershed to establish a value of SS.

2. Another method, as presented by Linsley, Kohler, and Paulhus (21, p. 250), consists of plotting the stream profile (elevation against distance) and determining the area under the profile. The mean slope is then taken to be the slope of a straight line which has the same area under it as the area under the profile.

3. Wentworth (38) discusses a simplified random method of determining the average slope of land surfaces.

$\boxed{L}$ - is the mean overland flow path length in feet.

Determination of L:

1. According to Chow (5 , p. 4-47), "An average length can be computed from measurements of a number of paths emanating from points uniformly spaced around the entire basin perimeter or extended upward from uniformly spaced points along the channel."

2. Balk's approach (2, p. 74), similar to that outlined by Chow, was to divide the periphery of the watershed boundary, on a topographic map with a contour interval of 5 feet and a scale of 1 inch equals 400 feet, into 200 foot increments. Then, at each increment point, he measured the distance, perpendicularly across the contours, to the nearest channel. These values were then averaged to give an index value of SS.

$\boxed{NN}$ - is the average Manning roughness coefficient for overland flow on soil surface. Increasing values of NN reduces runoff volumes and tends to attenuate the flood peaks by allowing more time for infiltration.

Determination of NN:

1. NN may be estimated from Table 4.

TABLE 4.

Manning's Roughness Value for Overland Flow for Various Surface Types
(After Clarke, 6, p. 74)

Watershed Surface	Manning's n
Smooth Asphalt	0.012
Asphalt or Concrete Paving	0.014
Packed Clay	0.030
Light Turf	0.200
Dense Turf	0.350
Dense Shrubbery and Forest Litter	0.400

2. Also see Chow, V. T., Open Channel Hydraulics, McGraw-Hill, New York, 1959, pp. 108-114.

3. Local offices of the Geological Survey usually have data on channel roughness.

NNU - is the average Manning roughness coefficient for overland flow on impervious surfaces.

Determination of NNU

1. NNU may be estimated using the same sources as discussed under NN.

IRC - is the daily interflow recession constant. This value controls the rate at which water passes through the upper soil zones.

Determination of IRC:

1. IRC may be estimated by graphical techniques for hydrograph analysis developed by Barnes (3 , p. 106).

2. Owen (28) has developed a computer program, based on the Barnes' method, to determine and display interflow and baseflow recession constants.

3. Clarke (6) established a range of from 0.62 to 0.82 for various watersheds in Kentucky.

4. Briggs (4) chose a value of 0.001 for Little Mill Creek.

5. Drooker (8) found a value of .7 for Hubbard Brook.

6. Ligon, Law, and Higgins (20) used a value of 0.40 for Clemson Research Watershed.

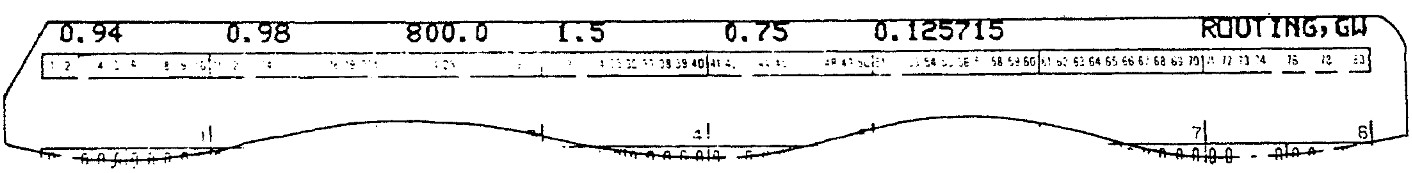
7. See Modification of Parameters for further discussion.

8 Channel Routing and Groundwater Parameters

The channel routing aspects of the model have received much attention and modification by users. For example, the routing parameters that follow have been developed by James. Also, firms like Hydrocomp International (12) have spent much effort in programming details of the routing stages throughout the watershed.

Read: KSC, KSF, CHCAP, RFC, KV24, KK24, from one card with 5F10.3, F20.18 Format.

Example of Input - Shown below is a typical example of an input card for the Channel Routing and Groundwater Parameter data.



$\boxed{\text{KSC}}$ - is the streamflow routing parameter for low flows. KSC is used to account for channel storage when channel flows are less than one-half of the channel capacity.

Determination of KSC:

The following formula is used to determine KSC and KSF:

$$\text{KSC or KSF} = \frac{K - 0.5t}{K + 0.5t}$$

where t is the routing period. K, as explained by Johnstone and Cross (18), can be determined using:

$$K = - Q \Big/ \frac{dQ}{dt}$$

where $\frac{dQ}{dt}$ is the slope of a line tangent to the hydrograph at the point of contraflexure, and Q is the surface runoff flow rate at the point of contraflexure. A hydrograph with inbank flows should be used.

$\boxed{\text{KSF}}$ - is a streamflow routing parameter for flood flows. KSF is used to account for channel plus flood-plain storage when streamflows are greater than twice the channel capacity.

Determination of KSF:

1. KSF can be calculated using the formulas as discussed above for KSC. However, a hydrograph of flood flows should be used.

$\boxed{\text{CHCAP}}$ - is the index capacity of the existing channel in cubic feet per second.

Determination of CHCAP:

1. Balk (2, p. 77) suggested that CHCAP might be estimated

by determining the gage height at bankfull flow, then reading the capacity directly from the rating curve.

2. CHCAP may be determined from hydraulic analysis of the profile and cross-section of the stream channel. Note, however, that topographic maps, unless of very large scale, will not provide enough detail to determine CHCAP by hydraulic analysis.

$\boxed{\text{RFC}}$ - is a parameter for nonlinear routing.

Determination of RFC:

This parameter is used for nonlinear routing in the subroutine "RTVARY". This subroutine is not in operation in the O.S.U. Version; therefore, any non-zero number may be used for RFC.

$\boxed{\text{KV24}}$ - is a daily baseflow recession adjustment factor. KV24 is used to provide a curvilinear base-flow recession (6, p. 46).

Determination of KV24:

1. There appears to be no method of predicting an initial value for KV24.

2. Balk (2, p. 78) suggests initializing KV24 equal to 1.0 to eliminate its influence on the base flow; then, from simulated hydrographs, adjust KV24 as necessary to better simulate groundwater flow.

3. Owen's (28) work with multiple baseflow recession constants will help to provide for curvilinear baseflow (see the following discussion on KK24).

4. Clarke (6) found a value of .99 on Cave Creek.

5. Briggs (4) chose a value of 0.75 for Little Mill Creek.

6. Ligon, Law, and Higgins (20) used a value of 0.36 for the Clemson Research Watershed.

7. Drooker (8) used a value of 0.99 for Hubbard Brook.

$\boxed{\text{KK24}}$ - is a daily baseflow recession constant which controls the rate of discharge from the goundwater table.

Determination of KK24:

1. KK24 can be estimated from graphical techniques as discussed by Barnes (3, p. 106).

2. For areas of stratified geology, particularly where continuous clay layers exist, a number of groundwater recession constants may be required to correctly develop the depletion curve. Owen (28) has studied this phenomenon in detail and has developed a separate program to determine and display (see Figure 4.) multiple recession constants. Further, he has modified the model (O.S.U. Version) to accommodate multiple recession constants. To use this option, one will have to study Owen's work in detail.

Note: If only one recession constant is required, the four cards (SM00015, SM00016, SM00017, SM00018), as shown in Appendix B, must be removed from the program.

3. See Modification of Parameters for further discussion.

11 Starting Moisture Storage Values as of October 1

Read: SGW, UZS, LZS, GWS from one card with 4F10.3 Format.

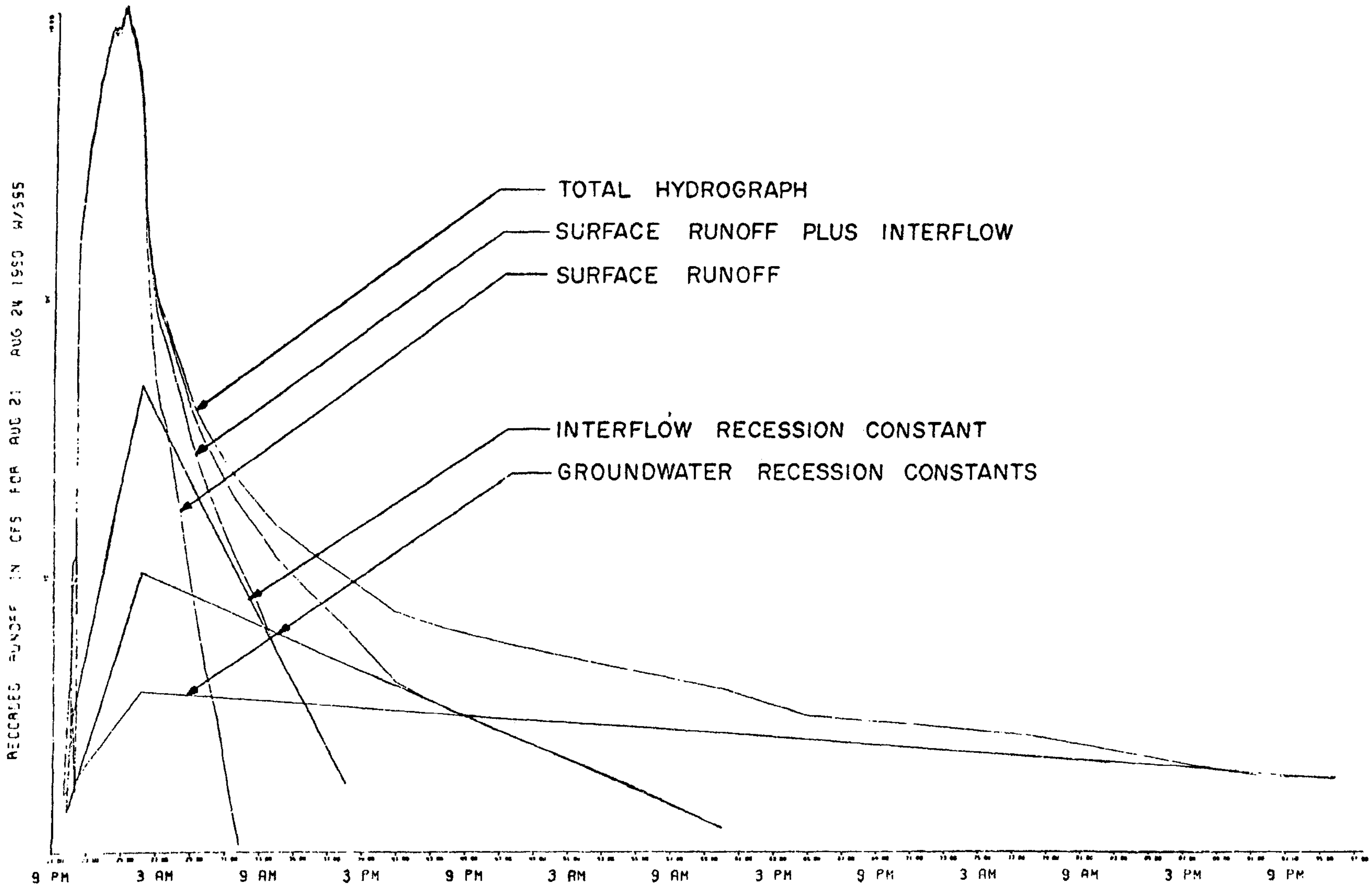
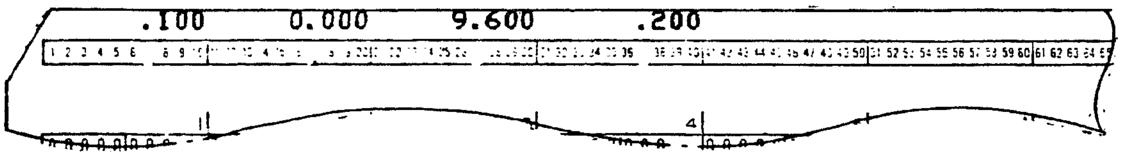


FIGURE 4. TYPICAL RECESSION ANALYSIS CURVE

(After Owen (28))

Example of Input - Shown below is a typical input card for the Starting Moisture Storage Value data.



SGW - is the groundwater storage increment, in inches, that reflects fluctuation in volume.

Determination of SGW:

1. An estimate of SGW can be made if detailed information on the behavior of groundwater fluctuations is available.

2. If the above information is not available, one must resort to trial and adjustment in accordance with the simulation results and the values of SGW returned by the model.

3. Briggs (4) used a value of 0.1 for Little Mill Creek.

4. Drooker (8) used a value of 1.0 for Hubbard Brook.

5. Ligon, Law, and Higgins used a value of 3.90 for Clemson Research Watershed.

Sources of Aquifer Data:

i. Geological Survey or Local Agencies (Groundwater Level Records)
ii. Geologic Profiles and Soil Maps

UZS - is the current volume, in inches, of soil surface moisture as interception and depression storage.

Determination of UZS:

1. UZS is normally zero unless there is precipitation during the last few days of September, causing the model to start the water year with some value.

$\boxed{\text{LZS}}$ - is the current soil moisture storage in inches. This represents the volume of water stored in the lower zone (between the groundwater table and the soil surface.

Determination of LZS:

1. Balk (2, p. 81) suggests that a rough estimate be used for the initial run; then, considering the values of LZS returned by the model, adjust LZS as necessary.
2. LZS will be some fraction of LZSN (Soil Moisture Storage Index); therefore, the methods used to calculate LZSN will be useful for initial estimates of LZS (see Soil Moisture Parameters (LZSN)).

$\boxed{\text{GWS}}$ - is the current value of the groundwater slope index in inches. It is an indication of the antecedent moisture conditions of the watershed.

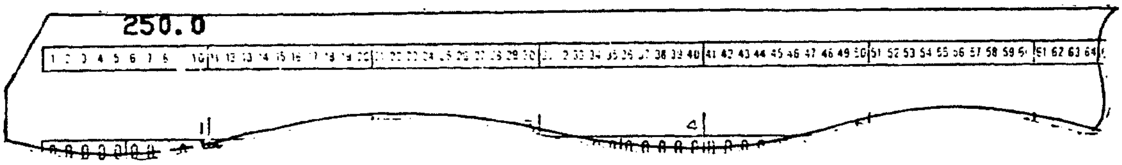
Determination of GWS:

1. Balk (2) suggests that GWS initially be set equal to SGW.
2. Briggs (4) suggests that initial values of GWS be between 0.15 and 0.25.
3. Ligon, Law, and Higgins (20) chose a value of 1.56 for Clemson Research Watershed.
4. Drooker (8) used a value of 0.5 for Hubbard Brook.
5. GWS can be adjusted in accordance with the simulation and the value of GWS returned by the model.

12 Swamp and Soil Crack Storage

Read: VOLUME from one card with F10.2 Format.

Example of Input - Shown below is a typical example of the card input for the Swamp and Soil Crack Storage data.



VOLUME - is the volume of water assigned to swamp storage and dry ground recharge in acre feet. It accounts for the runoff required to recharge swamps which, by middle to late summer, dry up. Also, under these dry spells, clayey coils will exhibit considerable shrinkage cracks.

Determination of VOLUME:

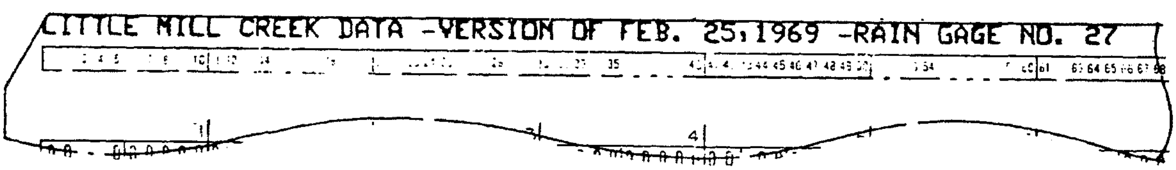
1. If there are no swamps, VOLUME equals 0.0.

2. If swamps dry up and the model is over simulating in the fall, the value of VOLUME may be estimated by planimetering the area between the recorded and simulated discharge curves, in second foot days, and converting it to acre feet.

13 Title of Computer Output (QQQ)

Read: Up to eighty characters from one card with a 20A4 Format.

Example of Input - Shown below is a typical input card for QQQ data.



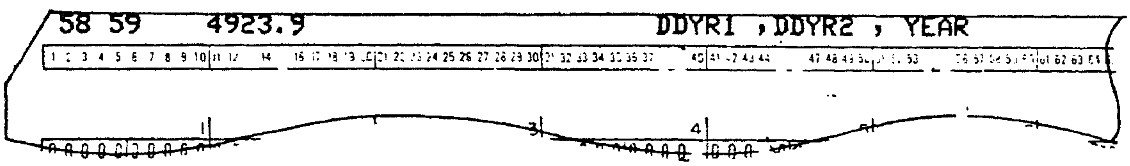
QQQ - Alphanumeric input to entitle the computer output.

Note: All the following data should be repeated in the following sequence, for each water year analyzed.

(14) New Year Identification Card

Read: DDYR1, DDYR2, YEAR from one card with 2I3, F10.1 Format.

Example of Input - Shown below is a typical example of card input for the New Year Identification data.



DDYR1 - Last two digits of the first year in the water year.

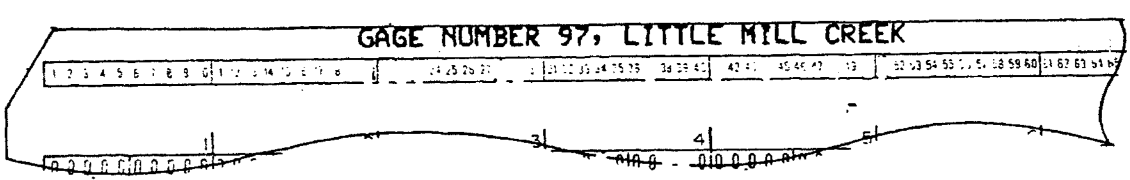
DDYR2 - Last two digits of the last year in the water year.

YEAR - Recorded annual streamflow for above water year in acre feet.

(15) Stream Gage Identification (QQO)

Read: Up to sixty characters from one card with 19X, 15A4 Format.

Example of Input - Shown below is a typical example of card input for the Stream Gage Identification data.

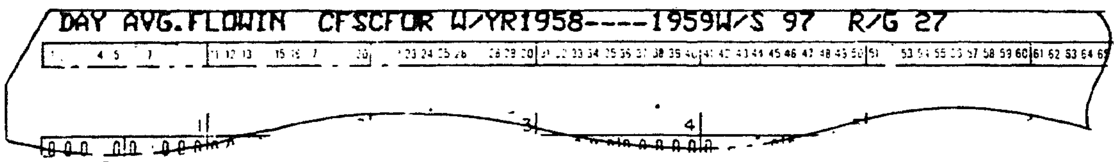


QQO - is alphanumeric input to identify the streamgage.

(16) Title of Ordinate for Runoff Hydrograph (QQY)

Read: Up to 56 characters from one card with a 1X, 14A4 Format.

Example of Input - Shown below is a typical example of card input for the Title of Ordinate for Runoff Hydrograph data.



QQY - is alphanumeric data for labelling the ordinate of the runoff hydrograph. This should be changed for each water-year and watershed. The data, one card in each year of data, consists of units of flow, the water year, the watershed number, and the raingage number.

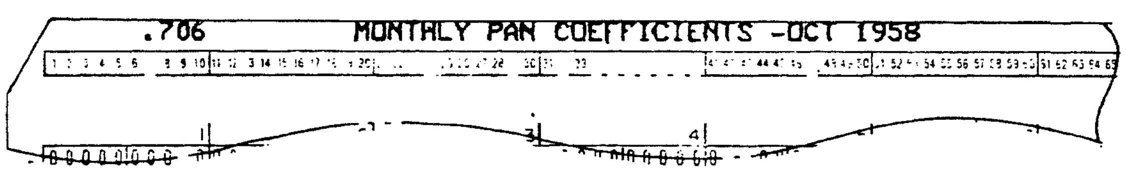
(17) Pan Evaporation Values

- See Evaporation Data, under Optional Input and Output (DKN(3)).

(18) Monthly Evaporation Pan Coefficients

Read: One value of EVCR from each of twelve cards (corresponding to the appropriate month) with F10.3 Format.

Example of Input - Shown below is a typical input card for the Monthly Evaporation Pan Coefficient data.



EVCR - Monthly Evaporation Pan Coefficient

Determination of EVCR:

1. Monthly pan coefficients may be determined by taking a ratio of the computed daily values of lake evaporation (averaged over the month) to the computed daily values of pan evaporation (averaged over the month).

2. Monthly pan evaporation coefficients may also be computed from methods set forth by Kohler (19).

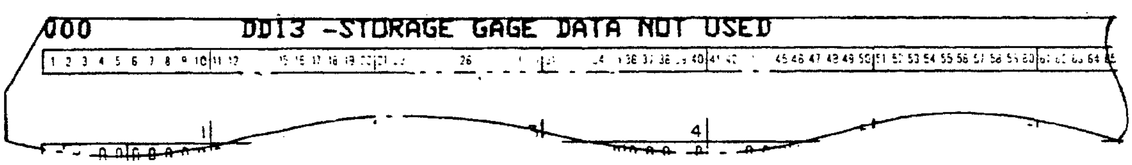
Data Sequence: October through December, January through September.

Source of Pan Coefficient Data - See Evaporation Data, under Optional Input and Output (DKN(3)).

(22) Storage (non-recording) Gage Rain Data

Read: One value of DD13 from one card with I3 Format.

Example of Input - Shown below is an example of an input card if no Storage Gage Rain Data are used.

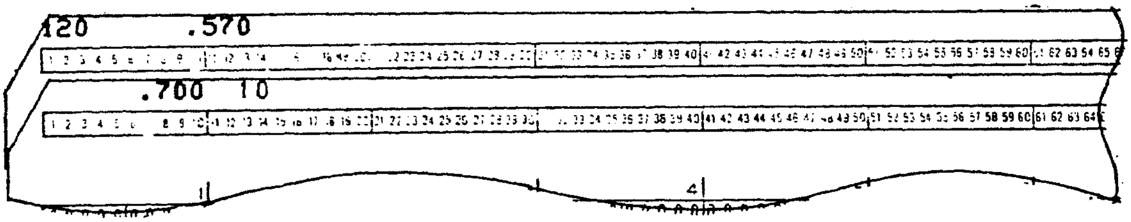


DD13 - Number of days (24 hour periods) of storage-gage input rainfall. If the hourly precipitation totals from an available recording gage provide representative patterns of basin-wide rainfall, the storage gage input data would not be used and DD13 would be set equal to zero. If DD13 is not equal to zero, the following additional inputs are required.

Read: WSG, SGRT from one card with F10.3, I4 Format.

Read: DD15, PREC from one card with I3, F10.3 Format.

Example of Input - Shown below is an example of a data set required if Storage Gage Rain Data is used.



WSG - is a storage gage weighting factor. According to Balk (2, p. 83), it is defined so that the average rainfall over the basin is the product of WSG and the storage gage rainfall plus the product of (1 - WSG) and the recording gage rainfall.

SGRT - is the hour of the day at which the storage gage rainfall is always read (0 to 24).

DD15 - is the day of the year for the corresponding storage gage rainfall. January 1 through December 31 corresponds to 1 through 365 on the data card. February 29 equals 366.

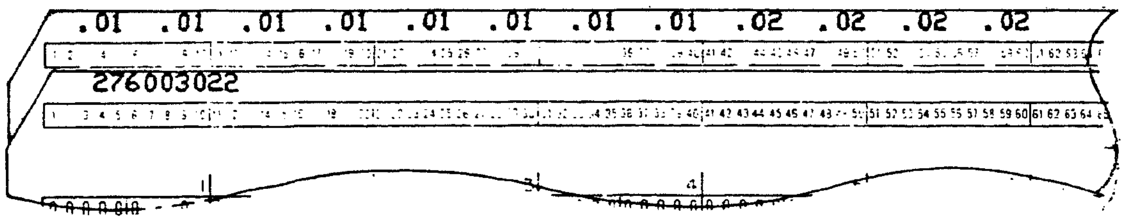
PREC - is the storage gage daily (24 hour period) rainfall total in inches.

23 Hourly Rainfall Data from Recording Gage

Read: ST, YR, MO, DAY, CN from one card with I5, 3I2, I1 Format.

Read: Twelve values of P1 (corresponding to the twelve hours of A.M. or P.M.) from one card with a 12F5.2 Format.

Example of Input - Shown below is a typical example of card input if rainfall occurs within a twelve hour period.



ST - is the number assigned to recording rain gage by U.S. Weather Bureau or some other identification number.

YR - indicates the last two digits of calendar year.

MO - is the month of the year.

DAY - is the day of the month.

CN - indicates ante or meridiem, 1 = A.M., 2 = P.M.

Note: This data is used to identify the P1 data described next. If no rainfall occurs in a twelve hour period, no input card is required.

P1 - is the hourly recorded rainfall array in inches. If there is no rainfall for a twelve hour period, no input card is required.

Data Sequence: October 1 through December 31, January 1 through February 28, February 29 (if leap year), March 1 through September 30.

Note: A sentinel card must be used to indicate that all precipitation data for a water year has been read. The sentinel card includes ST, YR, MO, DAY, CN from one card with I5, 3I2, I1 Format; however, YR = 98.

Sources of Precipitation Data:

i. Weather Bureau Stations
ii. Local Climatological Data (36)
iii. Hourly Precipitation Data (35)

Basic Output

The model, if no additional output options are called, will provide a basic output of synthesized and recorded data as shown in Figure 5 and discussed below. (corresponds to items on **Figure 5.**)

1 This table presents the synthesized average daily streamflow rates, in cubic feet per second, for each day of the year.

2 SYN STREAMFLOW - Summation of all the synthesized daily average flow rates, in cubic feet per second, for each month followed by the annual total.

3 TOT SYN VOL - Synthesized monthly and annual totals of runoff in inches over the watershed.

4 INTERFLOW VOL - Synthesized monthly and annual totals of interflow in inches over the watershed.

5 BASE FLOW VOL - Synthesized monthly and annual totals of baseflow in inches over the watershed.

6 ANNUAL SYNTHESIZED STREAMFLOW IN ACRE FEET - The volume of synthesized streamflow runoff from the watershed for the entire water year in acre feet.

⟨7⟩ REC STREAMFLOW - Summation of all the recorded daily average streamflow rates, in cubic feet per second, for each month followed by the annual total.

⟨8⟩ RECORDED VOLUME IN INCHES PER YEAR - Recorded annual total of runoff in inches over the watershed.

⟨9⟩ RECORDED VOLUME IN INCHES PER YEAR FROM NOV. THRU MARCH - Recorded volume, in inches over the watershed, from November through March. This is valuable in studying snowmelt problems.

⟨10⟩ AMOUNT OF SYNTHESIZED SNOW FROM NOV. THRU MARCH IN EQUIVALENT INCHES OF WATER - Valuable in snowmelt analysis.

⟨11⟩ ANNUAL RECORDED STREAMFLOW IN ACRE FEET - The volume of recorded streamflow runoff from the watershed for the entire water year in acre feet.

⟨12⟩ REC PRECIP - Summation of recorded precipitation, in inches, for each month followed by the total for the year.

⟨13⟩ SYN E.T.-NET - Synthesized monthly and annual totals of evapotranspiration in inches.

⟨14⟩ POTENTIAL E.T. - Monthly and annual recorded lake evaporation (potential) in inches.

⟨15⟩ STORAGES

UZS - End of the month values, in inches, of current surface moisture storage.

LZS - End of the month values, in inches, of current soil moisture storage.

SGW - End of the month values, in inches, for the groundwater storage fluctuation.

16 INDICES

UZSN - End of the month values, in inches, of the soil surface moisture storage index.

GWS - End of the month values, in inches, of the current values of the groundwater slope index.

EN - End of the month values of EN, a factor varying infiltration by season.

17 BALANCE - An annual moisture balance, in inches, which represents moisture not accounted for within the program.

Optional Input and Output

The following discussion covers additional program options (summarized in Table 5.) of the model which can be called at the discretion of the user to enhance and facilitate his analysis. Due to modification of the model by researchers, some of the original options, still within the program, have been phased-out and are now not operating.

LITTLE MILL CREEK DATA -VERSION OF FEB. 25,1969 -RAIN GAGE NO. 27

GAGE NUMBER 94, LITTLE MILL CREEK WATER YEAR 1960-61 U.S.U. WATERSHED MODEL

(1)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
1	0.192	0.045	0.741	0.466	0.461	1.766	13.752	1.548	7.056	0.442	0.926	0.146
2	0.186	0.044	1.081	0.442	0.426	1.633	2.406	1.430	27.747	0.410	1.123	0.141
3	0.175	0.041	1.117	0.416	0.394	1.509	1.395	1.322	1.672	0.381	1.049	0.140
4	0.162	0.038	1.081	0.390	0.365	13.933	1.288	1.221	1.174	0.352	0.970	0.130
5	0.150	0.044	1.017	0.558	0.337	25.053	1.190	1.129	1.085	0.328	0.897	0.120
6	0.138	0.057	0.945	1.673	0.313	13.235	1.100	1.063	1.003	0.305	0.829	0.111
7	0.128	0.067	0.879	3.339	0.305	2.277	1.025	1.381	0.927	0.282	0.766	0.102
8	0.118	0.065	0.815	2.050	0.329	15.354	0.948	19.205	4.625	0.261	0.709	0.095
9	0.122	0.090	0.755	1.276	0.527	3.565	11.412	13.717	4.652	0.241	0.656	0.088
10	0.117	0.145	0.698	1.577	0.519	2.190	12.238	1.502	7.004	0.223	0.622	0.081
11	0.109	0.135	0.646	3.825	0.739	2.030	1.559	1.256	2.371	0.206	0.595	0.075
12	0.100	0.125	0.597	2.249	1.509	1.879	9.248	1.161	1.856	0.191	0.550	0.069
13	0.093	0.115	0.553	1.415	3.110	1.975	5.369	1.073	1.716	0.176	0.509	0.064
14	0.086	0.107	0.516	1.310	1.123	2.166	1.374	0.991	1.651	0.163	0.471	0.059
15	0.079	0.099	0.486	2.609	0.807	1.642	1.244	2.824	1.536	0.152	0.435	0.055
16	0.073	0.095	0.452	1.974	0.746	1.515	19.713	2.778	1.415	0.142	0.405	0.051
17	0.068	0.089	0.424	1.224	1.810	1.400	4.176	0.994	1.308	0.131	0.380	0.047
18	0.063	0.082	0.510	1.851	7.073	1.356	3.010	1.140	1.209	0.122	0.351	0.043
19	0.061	0.076	0.471	1.478	2.128	1.890	1.912	1.069	1.117	0.146	0.325	0.040
20	0.061	0.070	0.381	1.163	1.206	1.282	1.761	0.926	1.032	0.165	0.300	0.037
21	0.057	0.065	0.354	1.082	1.113	3.199	24.441	0.856	0.954	0.153	0.286	0.034
22	0.052	0.063	0.329	1.005	2.228	2.325	16.533	0.791	0.882	0.141	0.277	0.032
23	0.048	0.087	0.305	0.932	3.906	4.117	5.761	0.731	0.823	0.150	0.257	0.029
24	0.045	0.081	0.282	0.863	1.437	1.826	1.865	0.676	0.766	0.263	0.237	0.027
25	0.041	0.074	0.539	0.798	43.768	1.719	77.272	0.625	0.708	0.490	0.228	0.028
26	0.038	0.069	0.737	0.738	61.385	1.499	28.789	0.597	0.655	0.368	0.233	0.027
27	0.036	0.064	0.553	0.683	2.875	1.385	2.234	0.554	0.605	0.340	0.216	0.025
28	0.034	0.059	0.485	0.631	1.911	1.280	2.625	0.512	0.560	0.315	0.199	0.023
29	0.031	0.076	0.453	0.583		1.183	1.924	0.474	0.517	0.782	0.184	0.021
30	0.029	0.075	0.423	0.539		1.093	1.675	0.438	0.478	0.596	0.171	0.020
31	0.035		0.438	0.499		1.096		0.416		0.768	0.158	

(2)	SYN STREAMFLOW	3.	2.	13.	40.	143.	118.	259.	64.	79.	9.	15.	2.	754.	CFSD
(3)	TOT SYN VOL	0.043	0.037	0.299	0.622	2.242	1.857	4.068	1.010	1.237	0.144	0.240	0.031	11.83	IN/YR
(4)	INTERFLOW VOL	0.000	0.000	0.011	0.166	1.756	1.026	2.537	0.505	0.680	0.009	0.000	0.000	6.689	IN/YR
(5)	BASE FLOW VOL	0.043	0.037	0.289	0.456	0.397	0.802	0.746	0.468	0.536	0.135	0.240	0.031	4.182	IN/YR
(6)	ANNUAL SYNTHESIZED STREAMFLOW IN ACRE FEET													1495.	ACFT
(7)	REC STREAMFLOW	5.	9.	5.	20.	112.	211.	294.	81.	43.	53.	17.	6.	856.	CFSD
(8)	RECORDED VOLUME IN INCHES PER YEAR													13.43	IN/YR
(9)	RECORDED VOLUME IN INCHES PER YEAR FROM NOV. THRU MARCH													5.60	IN/YR
(10)	AMOUNT OF SYNTHESIZED SNOW FROM NOV. THRU MARCH IN EQUIVALENT INCHES OF WATER													3.25	INCHES
(11)	ANNUAL RECORDED STREAMFLOW IN ACRE FEET										(1698.)			1697.	ACFT
(12)	REC PRECIP	1.81	1.82	1.60	0.91	3.93	3.54	6.37	2.65	2.97	5.64	2.17	0.95	34.36	IN/YR
(13)	SYN E.T.-NET	1.834	0.962	0.512	0.569	0.848	1.638	1.809	2.864	3.182	3.431	4.360	2.534	24.543	IN/YR
(14)	POTENTIAL E.T.	1.981	0.962	0.512	0.569	0.848	1.681	1.809	3.644	4.694	4.502	4.404	3.858	29.464	IN/YR
(15)	STORAGES-UZS	0.526	1.237	0.373	0.190	0.371	0.264	0.138	0.288	0.0	2.582	0.0	0.0		IN/YR
	LZS	6.770	6.861	7.496	8.059	8.660	8.950	9.478	8.301	7.171	6.624	6.867	5.278		IN/YR
	SGW	0.009	0.014	0.096	0.076	0.367	0.228	0.321	0.117	0.092	0.121	0.030	0.004		IN/YR
(16)	INDICES-UZSN	0.432	0.253	0.250	0.250	0.290	0.493	0.537	1.040	1.315	1.049	1.133	1.030		
	GWS	0.119	0.073	0.221	0.320	0.645	0.639	0.795	0.471	0.435	0.310	0.185	0.076		
	EN	0.649	0.500	0.500	0.500	0.500	0.500	0.500	2.875	9.769	8.553	8.859	6.598		
(17)	BALANCE	-0.0766	INCHES												

FIGURE 5. MODEL SIMULATION RESULTS-BASIC OUTPUT

TABLE 5.

Additional Program Options - DKN(X)

(X)	Function
1	Print Selected Storm Details
2	Infiltration Rate Factor Adjustment
3	Read Evaporation Data
4	Statistical Evaluation of Simulation Success
5	Print 20 Top Hourly Rainfall and Runoff Events
6	Print Daily Soil Moisture Storage Values
7	Read Snow Data
8	Multiple Precipitation Input (Non-Operable)
9	Read Recorded Streamflows
10	Combination of Several Basins (Non-Operable)
11	Read Diverted Flow
12	Hourly Routing of Streamflow (Non-Operable)
13	Modified Routing (Non-Operable)
14	Print Recorded Streamflow
15	Echo Check of Input Data
16	Logarithmic Hydrograph Plot
17	Arithmetic Hydrograph Plot
18	Details of Internal Program Function Values
19	Print Snowmelt Details
20	Arithmetic Hydrograph Plot for Selected Storm

9 DKN(1) - Selected Storm Details

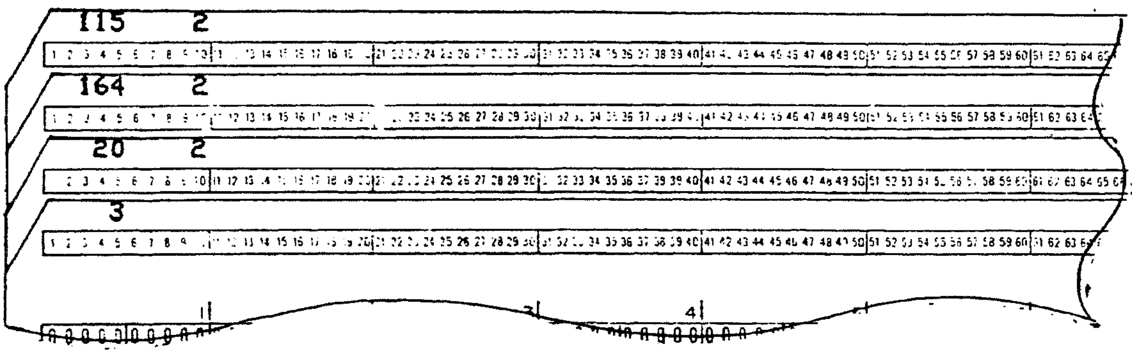
Description - If DKN(1) equals 1, the program prints out end-of-the-routing-interval values of rainfall, surface runoff, interflow, baseflow, total flow entering the channel and routed outflow for one select storm during each year of data. If DKN(1) equals 0, the program does not print out these values. Note: This option does not work at the end of a water year. For example, it will not print out a storm which begins on September 30 and ends on October 2.

Input - If DKN(1) equals 1

Read: One value of YRDET on one card in an I5 Format.

Read: IOUT, INUM from each of YRDET number of cards with a 2I5 Format.

Example of Input - If 3 years of data are being analyzed and 2 days of details are desired for a January 20th storm in the first year, a June 13th storm in the second year, and an April 25th storm in the third year, the card input would appear as follows:



YRDET - Number of years of data being analyzed.

IOUT - Day number of the calendar year for the beginning of a storm for which detailed output is requested.

INUM - Number of elapsed days for which detailed output is requested.

Note: If DKN(1) equals 1, IOUT and INUM must be read for all years analyzed.

Explanation of Output

The output of DKN(1) is in tabular form with the following table headings:

RAINFALL DEPOSITION

DY - Day of month that detailed storm output is requested.

HR - Particular hour of the day for which detailed storm output is requested.

PD - Period of the hour of output requested. For example, if the routing interval is 5 minutes, PD will range from 1 to 12.

RAIN - Current rainfall rate (inches per routing interval increment).

ENTRUZ - Current rainfall rate (inches per routing interval increment) minus the residual rainfall after soil surface moisture depletion (inches).

ENTRLZ - Residual rainfall after soil surface moisture depletion (inches) minus the sum of current moisture entering surface runoff plus interflow (inches).

INTFST - Water entering interflow storage (inches).

OVFLST - Current direct runoff (inches).

MOISTURE STORAGE

UZS - Current soil surface moisture storage (inches).

LZS - Current soil moisture storage (inches).

SRGX - Current water in interflow storage (inches).

QVLDST - Total carryover overland flow storage for pervious and impervious surfaces (inches).

STREAMFLOW ORIGIN

DIRRNF - Current overland flow reaching stream from pervious and impervious surfaces (inches).

INTFRF - Current rate at which interflow is entering the channel (inches per hours).

BASEFLW - The product of the selected routing time increment and the baseflow (inches per hour) minus the watershed evaporation from exposed water surfaces (inches per hour).

TOTFLW - Direct runoff plus interflow (inches/routing interval) plus BASEFLW.

STREAM OUTFLOW

INCHES - Product of the routing interval and the current synthesized streamflow (cubic feet per second), all divided by flow rate equalling one inch per hour of discharge from the watershed.

CFS - Current synthesized streamflow (cubic feet per second).

DKN(2) - Infiltration Rate Factor Adjustment

Description - If DKN(2) equals 1, the program adjusts the input infiltration rate factor (C2) to make the synthesized results more in line with the recorded ones (see Subroutine "TEST"). If DKN(2) equals 0, the program uses the input factor without adjustment.

Note: To use this option, one must also call option 9.

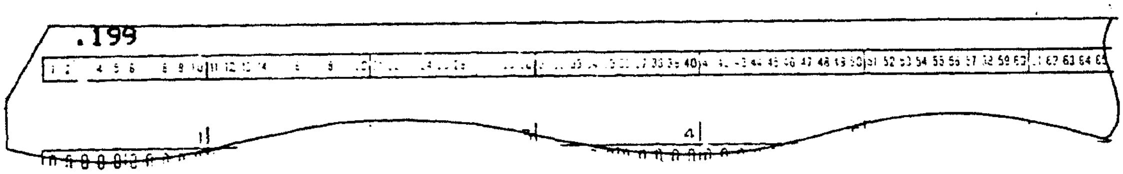
17 DKN(3) - Evaporation Data

Description - If DKN(3) equals 1, the program reads in average daily evaporation over ten-day periods. If DKN(3) equals 0, the program reads daily evaporation values for 365 or 366 days.

Input - If DKN(3) equals 0

Read: One value of E from 365 or 366 cards with a F6.3 Format.

Example of Input - Shown below is a typical example of an input card for Evaporation data.



$\boxed{E}$ - Pan evaporation for one day in inches.

Data Sequence: October 1 through December 31, January 1 through February 28, February 29 (if leap year), March 1 through September 30.

Input - If DKN(3) equals 1

Read: One value of E from 37 cards with a F6.3 Format.

Example of Input - Same as above.

$\boxed{E}$ - Pan evaporation for ten day averages in inches.

Data Sequence: October 1 through December 31, January 1 through September 30.

Sources of Evaporation Data:

i. Weather Bureau Stations (Class A pan records)
ii. Climatological Data (34)
iii. Kohler (19) describes an empirical relation for estimating pan evaporation from pertinent meteorlogical factors.

DKN(4) - Statistical Evaluation of Simulation Success

Description - If DKN(4) equals 1, the program prints out a daily flow error table (statistical evaluation of the simulation) at the end of the year. If DKN(4) equals 0, the program neither calculates nor prints out daily flow errors.

Note: To use this option, one must also call option 9.

Explanation of Output

Figure 6. shows a typical example of the DAILY FLOW DURATION

AND ERROR TABLE. An explanation of the table headings and output follows:

FLOW INTERVAL - Assigned flow intervals.

CASES - Number of days when the recorded mean daily flow was within the assigned interval.

AV. ERROR - Average error in the simulated flows. This shows the departure of the daily synthesized flows from the daily recorded flows.

AVR. ABS. ERROR - Average absolute error in the mean daily simulated flows.

STANDARD ERROR - Standard error in the mean daily simulated flows.

At the base of this table is a summary. Under CASES, the total number of days is given. Under AV, ERROR, the value given is calculated by multiplying the AV. ERROR times the corresponding number of CASES, adding these values, and then dividing the total by the total number of CASES. Under STANDARD ERROR, the value is a summation of the standard errors for each interval.

CORRELATION COEFFICIENT - The correlation coefficient is obtained by matching the simulated and recorded flows for each day. The average daily streamflow correlation coefficient, computed by statistical analysis, may be controlled by how closely the synthesized and recorded peak flood flows match. On the other hand, in area where the number of runoff events is few, the coefficient may be deceptively high, since it is

DAILY FLOW DURATION AND ERROR TABLE

FLOW INTERVAL	CASES	AV.ERROR	AVR. ABS. ERROR	STANDARD ERROR
0. -	145.0	0.3	0.52	0.69
1.0-	38.0	0.0	0.54	0.66
1.6-	27.0	-0.2	0.78	0.96
2.7-	56.0	-0.4	1.05	1.46
4.5-	35.0	-1.5	2.26	2.71
7.4-	34.0	-2.0	5.59	7.35
12.2-	14.0	-2.6	7.04	7.69
20.1-	10.0	-1.8	12.22	15.46
33.1-	2.0	-13.4	13.36	4.49
54.6-	1.0	27.6	27.58	
90.0-	1.0	-14.3	14.31	
148.4-	0.			
244.7-	1.0	-12.2	12.16	
403.4-	1.0	-145.0	144.99	
665.1-	0.			
1096.6-	0.			
1808.0-	0.			
2981.0-	0.			
4914.8-	0.			
8103.1-	0.			
13359.7-	0.			
22026.5-	0.			
	365.0	-0.9	2.44	41.46

CORRELATION COEFFICIENT (DAILY) 0.9851

TWENTY HIGHEST CLOCKHOUR RAINFALL EVENTS IN THE WATER YEAR

0.970 0.710 0.560 0.540 0.540 0.530 0.520 0.490 0.490 0.470 0.460 0.440 0.430 0.360 0.360 0.350 0.350 0.350 0.340 0.340

TWENTY HIGHEST CLOCKHOUR OVERLAND FLOW RUNOFF EVENTS IN THE WATER YEAR

0.268 0.254 0.201 0.164 0.162 0.083 0.052 0.051 0.048 0.037 0.027 0.026 0.020 0.019 0.017 0.010 0.008 0.006 0.004 0.004

FIGURE 6. DAILY FLOW DURATION AND ERROR TABLE
(After Balk(2))

strongly influenced by a large number of near zero events. Therefore, careful consideration must be given to what the correlation coefficient is actually indicating.

DKN(5) - 20 Top Hourly Rainfall and Runoff Events

Description - If DKN(5) equals 1, the program prints out the 20 top hourly recorded rainfall events (inches) and the 20 top hourly synthesized runoff events (inches) during the year. If DKN(5) equals 0, the program does not print out these values.

Explanation of Output

Figure 4.6 shows the output from DKN(5). The values are presented in descending order of magnitude.

DKN(6) - Soil Moisture Storage Values

Description - If DKN(6) equals 1, the program prints out, in tabular form, the daily values of the current soil moisture storage (LZS), in inches. If DKN(6) equals 0, the program does not print out these values.

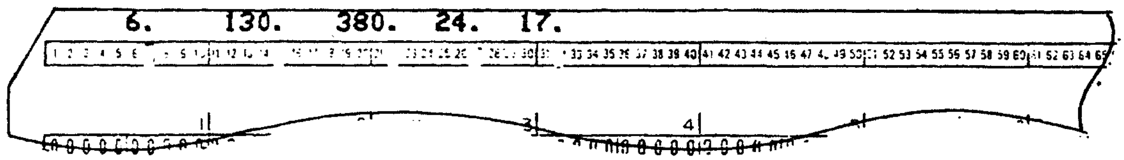
21 DKN(7) - Snow Data

Description - If DKN(7) equals 1, the program reads additional data and uses it to provide for snowfall and snowmelt. If DKN(7) equals 0, the program treats all precipitation as rainfall.

Input - If DKN(7) equals 1

Read: TDPT, VW, ALANG, TMAX, TMIN from each of 151 or 152 cards with an F7.0, F8.0, F7.0, 2F5.0 Format.

Example of Input - Shown below is a typical example of an input card for Snow data.



TDPT - Recorded daily average dewpoint temperature in ^{o}F.

VW - Total daily wind movement in miles per day.

ALANG - Total daily solar radiation in Langleys per day.

TMAX - Daily maximum temperature in ^{o}F.

TMIN - Daily minimum temperature in ^{o}F.

Sources of Climatological Data:

i. Weather Bureau
ii. Climatological Data (34)
iii. Local Climatological Data (36)
iv. Climatic Guide (33)

Data Sequence: November 1 through December 31, January 1 through February 28, February 29 (if leap year), March 1 through March 31.

Note: Mease (24) modified the original snowmelt subroutine by Linsley and Crawford (7) to handle snowmelt problems unique to Ohio. The original snowmelt subroutine was designed for areas where large inputs of snow are the major form of precipitation. The subroutine by Mease (24) is for sparse snow inputs and may have to be altered for different sections of the country.

DKN(8) - Multiple Precipitation Input

Description - If DKN(8) equals 1, the program accepts input from more than one recording raingage. If DKN(8) equals 0, the program accepts input from only one recording gage.

Note: This option is NOT OPERATING; always use 0.

19 DKN(9) - Recorded Streamflows

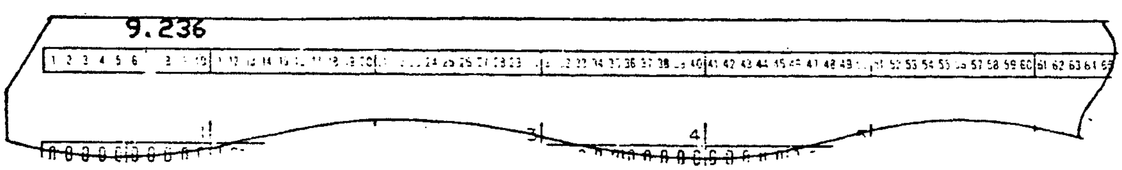
Description - If DKN(9) equals 1, the program reads 365 or 366 daily recorded streamflows (average flow for the day in cubic feet per second). If DKN(9) equals 0, the program does not read these values and statistical evaluation cannot be performed.

Note: If this option is not called, then option 2 and option 4 cannot be used.

Input - If DKN(9) equals 1

Read: One value of FLO from 365 or 366 cards with an F10.3 Format.

Example of Input - Shown below is a typical input card for FLO data.



FLO - Recorded daily average streamflow in cubic feet per second.

Sources of Streamflow Data:

i. Water Supply Papers, Geological Survey
ii. State Water Resource Commissions
iii. Field monitoring program - if the basin has not been gaged, one should attempt to immediately start a monitoring program to obtain streamflow records.

Data Sequence : October 1 through December 31, January 1 through February 28, February 29 (if leap year), March 1 through September 30.

DKN(10) - Combination of Several Basins

Description - If DKN(10) equals 1, the program will combine hydrographs for several basins in sequence. If DKN(10) equals 0, the program treats the basin as one homogeneous unit.

Note: This option is NOT OPERATING; always use 0.

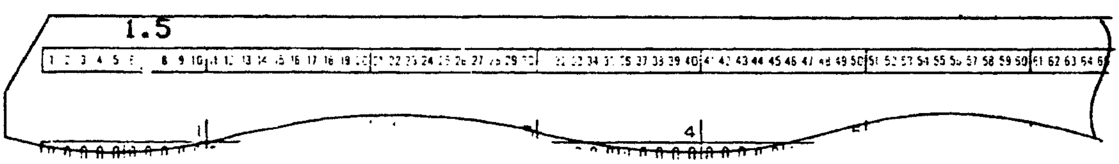
20 DKN(11) - Diverted Flows

Description - If DKN(11) equals 1, the program reads 365 or 366 daily values of flow diverted into or out of the basin. If DKN(11) equals 0, the program does not read these values.

Input if DKN(11) equals 1

Read: One value of SDIV per card from 365 or 366 cards with an F10.3 Format.

Example of Input - Shown below is a typical input card for SDIV data.



$\boxed{\text{SDIV}}$ - Daily average streamflow diverted into (+) or out of (-) the basin in cubic feet per second.

Data Sequence: October 1 through December 31, January 1 through February 28, February 29 (if leap year), March 1 through September 30.

DKN(12) - Hourly Routing of Stream

Description - If DKN(12) equals 1, the program routes streamflow on an hourly basis. If DKN(12) equals 0, the program routes streamflow on the selected routing time increment basis.

Note: The work by Valentine (37), on variable routing intervals, supersedes this option and makes it unnecessary (see Time of Concentration and Time Area Histogram under Required Input); always use 0.

DKN(13) - Modified Routing

Description - If DKN(13) equals 1, the program makes streamflow routing a function of discharge (see subroutine "RTVARY"). If DKN(13) equals 0, the program does not make the above change.

Note: This option is NOT OPERATING: always use 0.

DKN(14) - Recorded Streamflow Output

Description - If DKN(14) equals 1, the program prints out, in tabular form, the recorded average daily streamflow rates, in cubic feet per second, for each day of the year. If DKN(14) equals 0, the program does not print out these values.

DKN(15) - Echo Check of Input Data

Description - If DKN(15) equals 1, the program prints out all input data (echo check). If DKN(15) equals 0, the program prints out only the values of the program control array (DKN(1) through DKN(20)) and the input required for the detailed storm analysis.

2 DKN(16) - Logarithmic Hydrograph Plot

Description - This option is useful for analysis of simulation results, particularly for low flows and groundwater inputs to streamflow. If DKN(16) equals 1, the program calls for a logarithmic plot and the computer will punch out cards to plot the runoff hydrograph for every water year that is synthesized. These cards are then fed by the user to an I.B.M. 1130 or an I.B.M. 1627 computer that drives an I.B.M. 1627 plotter (or comparable facilities). If DKN(16) equals 0, the program does not call for the logarithmic plot.

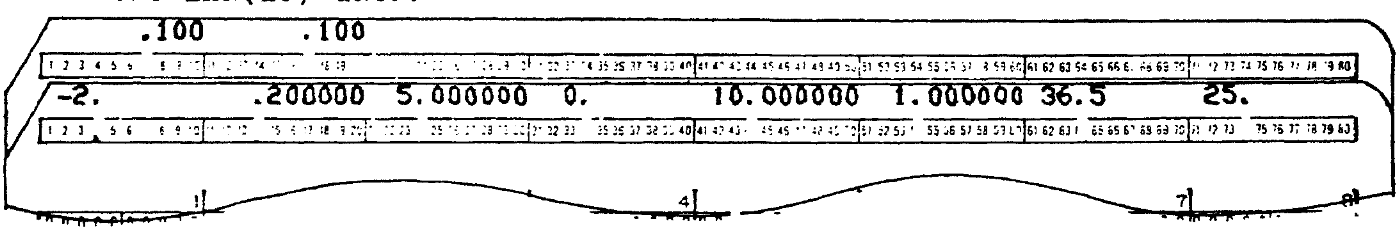
Note: To avoid confusion, if DKN(16) equals 1, let DKN(17) and DKN(20) equal 0.

Input - If DKN(16) equals 1

Read: DRORG, DELDR, DELDR1, DDRORG, DDELDR, DELDR2, AXISX, AXISY from one card with a 8F10.6 Format.

Read: DL, SL from one card with a 2F10.3 Format.

Example of Input - Shown below are typical input cards for the DKN(16) data.



DRORG - The numeric label for the minimum value of the ordinate at the axis origin for the logarithmic hydrograph.

DELDR - The number of cubic feet per second per inch of ordinate used in plotting the logarithmic hydrograph.

$\boxed{\text{DELDR1}}$ - The spacing between tic marks for the ordinate of the logarithmic hydrograph (inches).

$\boxed{\text{DRRORG}}$ - The numeric label for minimum value of the ordinate axis origin for the arithmetic hydrograph.

$\boxed{\text{DDELDR}}$ - The number of cubic feet per second per inch of ordinate used in plotting the arithmetic hydrograph.

$\boxed{\text{DELDR2}}$ - The spacing between tic marks for the ordinate of the arithmetic hydrograph (inches).

$\boxed{\text{AXISX}}$ - Length of abscissa for plotting hydrographs (inches).

$\boxed{\text{AXISY}}$ - Length of ordinate for plotting hydrograph (inches).

$\boxed{\text{DL}}$ - The dash length used in plotting the synthesized hydrographs (inches).

$\boxed{\text{SL}}$ - The space length used in plotting the synthesized hydrograph (inches).

2 DKN(17) - Arthmetic Hydrograph Plot

Description - In conjunction with the outputted simulated streamflow tables, this plot affords a very quick means of evaluating, by inspection, the degree of simulation success. If DKN(17) equals 1, the program calls for the arithmetic hydrograph plot. If DKN(17) equals 0, the program does not call for the arithmetic plot. The operating procedure is similar to that discussed under DKN(16).

Note: To avoid confusion if DKN(17) equals 1, let DKN(16) and DKN(20) equal 0.

Input - If DKN(17) equals 1

The additional input requirements for DKN(17) are similar to the input for DKN(16).

Explanation of Output

Figure 7. is an example of the arithmetic hydrograph plot from DKN(17).

DKN(18) - Details of Internal Program Function Values

Description - If DKN(18) equals 1, the program prints out SSEP, ISEP, EN, UZSN, UZS, GWS, SGW, SINT, SRGX, SSGWF, and LOS. These values are used to obtain a better indication of the model's interactions in the upper, lower, and deep lower zones. If DKN(18) equals 0, the program normally does not print out these values.

Explanation of Output

The output of DKN(18) is in tabular form with the following table headings:

SSEP - An evaporation parameter, in inches, used to vary infiltration (continually updated).

ISEP - An evaporation parameter, in inches, used to vary infiltration (constant for an entire water year).

EN - Factor varying infiltration by season (continually updated).

UZSN - Soil surface moisture storage index in inches (continually updated).

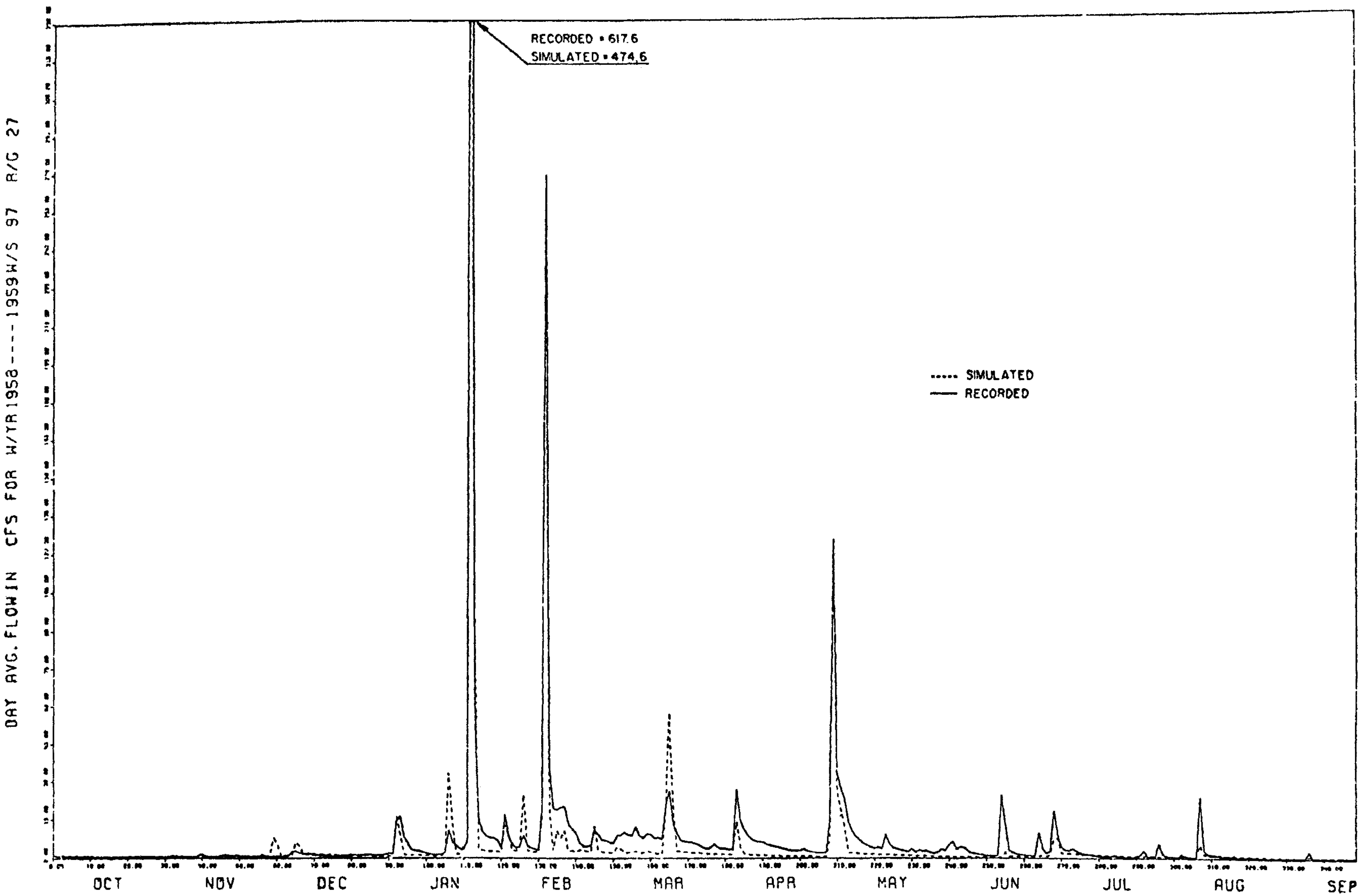


FIGURE 7. TYPICAL SIMULATED AND RECORDED ARITHMETIC HYDROGRAPH
(After Briggs(4))

UZS - Current soil surface moisture storage in inches (continually updated).

GWS - Current value of groundwater slope index in inches (continually updated).

SGW - Groundwater moisture storage in inches (continually updated).

SINT - Variable used to sum synthesized daily interflows in inches (starts at 0.0 at the beginning of each new month and is continually updated).

SRGX - Current water in interflow storage in inches (continually updated).

SSGWF - Variable used to sum synthesized daily base flows in inches. (Starts at 0.0 at the beginning of each new month and is continually updated.)

LOS - Groundwater evaporation in inches (continually updated).

DKN(19) - Snow Details

Description - If DKN(19) equals 1, the program will print out hourly values of TEMP, RM, CDM, CVM, RADM, LIQW, PACK, and PX. This data provides a detailed account of the snowpack accumulations and depletions during the five months of the snow season (November through March).

Note: Mease (24) suggests that only one year of data be run when the snow output option is called; otherwise, approximately 30,000 lines of snow details will be printed. To use this option, one must also call option 7.

Explanation of Output

The output of DKN(19) is in tabular form with the following table headings:

DAY - Particular day of the month.

HOUR - Current hour of the day.

TEMP. - Hourly calculated temperature over the watershed in ^{o}F.

RM - Melt due to rain in inches.

CDM - Condensation melt in inches.

CVM - Convection melt in inches.

RADM - Radiation melt in inches.

LIQW - Liquid water held in snowpack in inches.

PACK - Current snowpack water in inches.

RUNOFF - If snow is on the ground, it is the calculated amount of snowmelt in inches. If there is no snow, it is the average rainfall over the basin in inches.

(10) DKN(20) - Arithmetic Hydrograph Plot for Selected Storms

Description - If DKN(20) equals 1, the program calls for an arithmetic plot of synthesized stream outflow along with the rainfall hyetograph for one select storm during each year of data. If DKN(20) equals 0, the program does not plot these values. The operating procedure is the same as discussed under DKN(16).

Note: To avoid confusion, if DKN(20) equals 1, the let DKN(16) and DKN(17) equal zero. Also, to use this option, one must also call option 1.

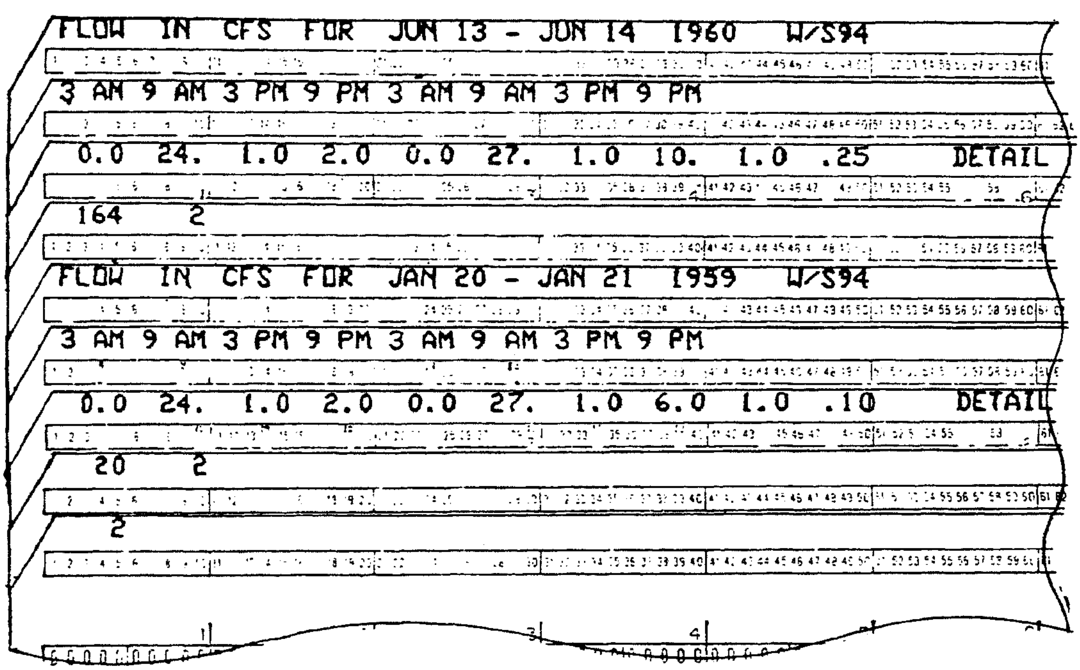
Input - If DKN(20) equals 1

Read: XORG, XAX, XTIC, XUNIT, YORG, YAX, YTIC, YUNIT, ZTIC and ZUNIT from one with a 10F5.2 Format for each year of record.

Read: X-Axis Label (DDX) for the selected storm, up to 32 characters on one card in a 8(1X, A4) Format.

Read: Y-Axis Label (DDY), up to 88 characters on two cards in a (20A4/2A4) Format.

Example of Input - Since DKN(20) and DKN(1) must be called simultaneously, a complete data set for both options will be shown. If, for example, two years of data are being analyzed and plots of two days duration are desired for a January 20th storm in the first year, and a June 13th storm in the second year, the following example data would be required:



XORG - Numeric label for the minimum value of the abscissa at the axis origin for the individual storm plot.

XAX - The length of abscissa for the individual storm plot.

XTIC - The spacing between tic marks for the abscissa of the detailed storm plot in inches.

XUNIT - The number of hours per inch of abscissa used in plotting the individual storm.

YORG - The numeric label for the minimum value of the ordinate at the axis origin for the detailed plot.

YAX - The length of ordinate for the detailed storm plot in inches.

YTIC - The spacing between tic marks for the ordinate of the storm plot in inches.

YUNIT - The number of cubic feet per second per inch of ordinate used in the selected storm plot.

ZTIC - The spacing between tic marks for the ordinate of the rainfall hyetograph plot in inches.

DDX - Label of abscissa for individual storm plot.

DDY - Label of ordinate for individual storm plot.

Explanation of Output

Figure 8. shows an example of the selected storm plot output of DKN(20).

Modification of Parameters

The final test, as to whether a given set of input parameters adequately characterize the watershed, is whether the

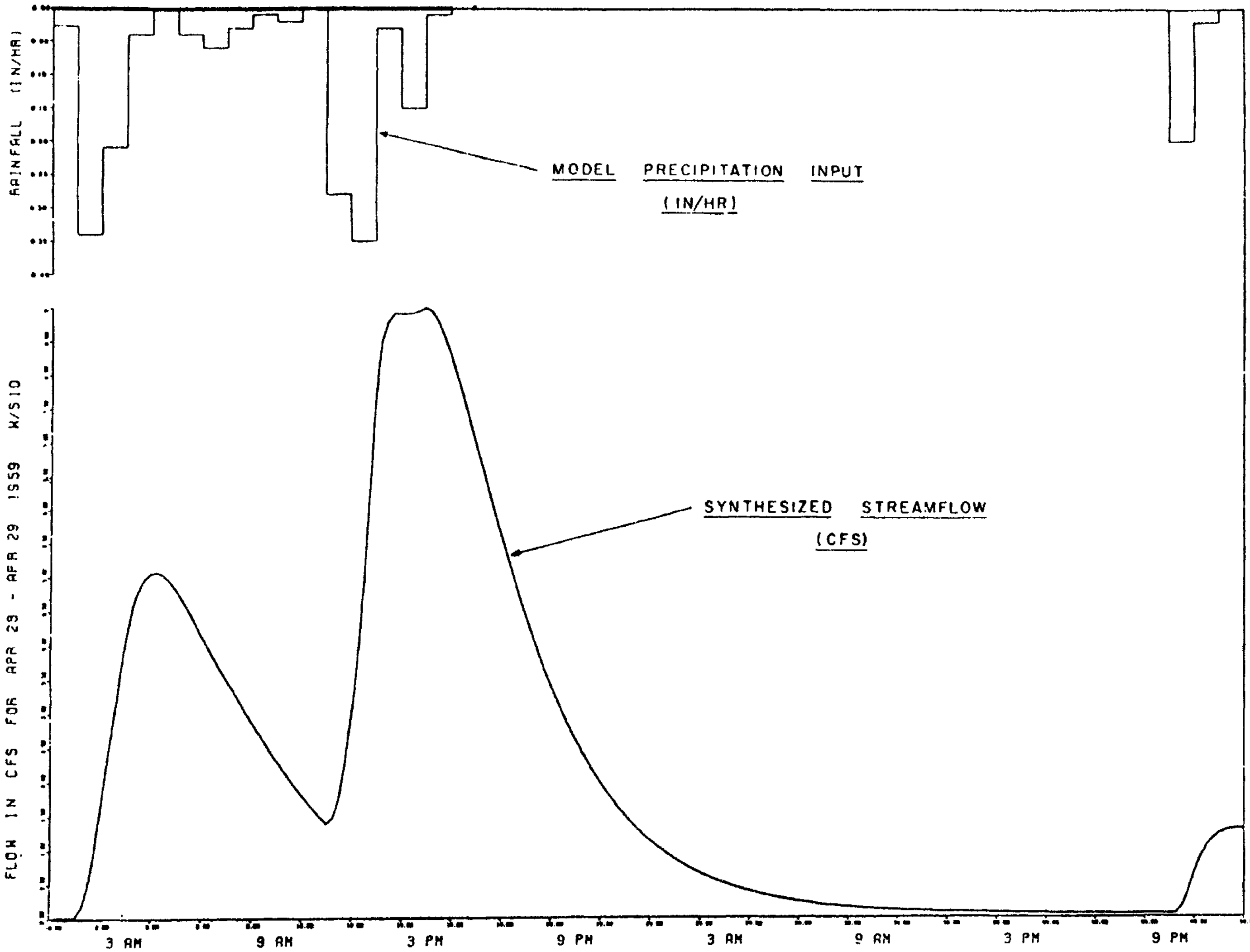


FIGURE 8. TYPICAL SYNTHESIZED HYDROGRAPH FOR A SELECTED STORM
(After Valentine(37))

simulated hydrograph matches the corresponding recorded hydrograph. Most of the difficulty in matching hydrographs arises from the lack of good quantitative data for many of the hydrologic components of the watershed. For example, initial values of infiltration, soil moisture, and groundwater storage generally must be estimated and thus, are subject to substantial error. The user's most difficult task, in modeling, will be adjusting the parameters, in accordance with hydrograph comparisons, to achieve meaningful simulations.

After each trial run, the user will have to compare the synthesized and the recorded hydrographs to decide which parameters should be altered for better results (see Logarithmic and Arithmetic Plot Options). This may be difficult since some of the parameters are strongly interdependent. However, since each parameter is tied to a well defined segment of the runoff cycle, the amount to vary each parameter can be based on questions such as whether more rapid or slower recessions will improve the simulation. In relation to this, Briggs (4) conducted a sensitivity study for the adjustment of basic input parameters which gives some valuable insight into how the model responds to changes in salient parameters.

In his sensitivity study, Briggs (4) chose parameters (LZSN, CB, EDF, K3, EF, EMIN, CX, EPXM, CY, KK24, IRC, GWS) which deal principally with the moisture balance of the watersheds and are not directly identifiable from the geomorphology of the area. The prime objective of his study was to balance the yearly runoff yield with secondary considerations given to the daily soil moisture values, hydrograph peak values, hydrograph recession flow, and the daily correlation coefficient. The results of Briggs' study are summarized in Table 6. Since it shows the relative effect of the changes in the more salient features in the simulation, it can be used as a guide in adjusting the values for the basin input parameters. Note, however, that Briggs' study (4) was for a particular area (Little Mill Creek near Coshocton, Ohio). The responses shown in Table 6. may not hold for basins with radically different indices. See Briggs (4) for additional information on each parameter of the table.

The parameter values are adjusted until the hydrograph synthesized by the computer model matches the recorded hydrograph with the desired precision; this will vary according to the needs of the particular study. It must be realized that one can never exactly match simulated and recorded hydrographs because of the actual limitations of the model and lack of consideration for variability of rainfall patterns from storm to storm. For example, in thunderstorms, rainfall is often reported at a gage when there is little or no rainfall on the rest of the watershed or vice versa. It should also be realized that, because of the interdependency of various parameters, it is possible that several combinations of parameters can produce nearly the same results.

Experience, ingenuity, familiarity with the model, under-

Key: ↑ Increased
↓ Decreased
---- Not Effected

* Slightly
** Moderately
*** Significantly

W - Winter
S - Summer

Selected Input		Simulation Feature								
Parameter	Parameter Change	Yield	Peaks		Interflow Recessions		Base Flow Recessions		Soil Moisture	
			W	S	W	S	W	S	W	S
LZSN	↑	*** ↓	** ↓	** ↓	** ↓	* ↓	** ↓	* ↓	*** ↑	*** ↑
CB	↑	*** ↓	*** ↓	*** ↓	** ↑	** ↑	* ↑	* ↑	*** ↑	*** ↑
EDF	↑	*** ↓	-----	*** ↓	-----	*** ↓	-----	** ↓	-----	* ↑
K3	↑	*** ↓	** ↓	** ↓	* ↓	* ↓	* ↓	* ↓	* ↓	* ↓
EF	↑	* ↓	-----	*** ↓	-----	** ↑	-----	** ↑	-----	* ↑
EMIN	↑	*** ↓	*** ↓	-----	** ↑	-----	* ↑	-----	** ↑	-----
CX	↑	* ↓	* ↓	* ↓	-----	-----	-----	-----	-----	-----
EPXM	↑	* ↓	* ↓	* ↓	-----	-----	-----	-----	-----	-----
CY	↑	-----	-----	-----	-----	-----	-----	-----	-----	-----
KK24	↑	* ↓	** ↓	** ↓	** ↓	** ↓	** ↑	** ↑	-----	-----
IRC	↑	-----	* ↓	* ↓	* ↓	* ↓	* ↓	* ↓	-----	-----
GWS	↑	-----	-----	-----	-----	-----	-----	-----	-----	-----

Summary of Results of the Sensitivity Study

TABLE 6.

(After Briggs (4))

standing of the sensitivity of simulated flow to specific adjustment, qualitative understanding of the hydrologic cycle, and a constant vigilance against unreasonable results will all help in adjusting parameters. It should be noted that, in addition to the parameter modifications which can be made, the user can modify the program to fit his own specific needs; this, however, is usually extremely time consuming.

ADDITIONAL SAMPLE VALUES OF MODEL PARAMETERS

The following information was abstracted from a report by Crawford (12') on the application of digital simulation to urban hydrology.

General Description of the Watersheds Modeled

Boneyard Creek, Champaign-Urbana, Illinois

A watershed containing portions of a University, residences, and commercially developed property. A large portion of the Watershed is drained by storm sewers and open channels. Channels are small and the flood plains are restricted by development.

Waller Creek, Austin, Texas

The upper portion of the basin has larger areas of undeveloped land than the lower one, creating considerable variation in impervious cover. The soil is clay underlain by chalk. Low flow are augmented by return flows of city water.

Echo Park, Los Angeles, California

The slopes are very steep with the upper basin mainly residented and and the lower commercial. About 20% of the watershed is impervious and directly storm sewered.

Land Parameters Values Used in the Model

	Boneyard Creek	Waller Creek	Echo Park
K1	1.05	1.01	1.00
A	0.12	0.12	0.18
EXPXM	0.10	0.10	0.15
UZSN	0.80	1.00	0.40
LZSN	7.50	8.00	5.00
K3	0.25	0.25	0.40
K24L	0.00	0.00	1.00
K24EL	0.00	0.00	0.00
INFILTRATION	0.05	0.04	0.03
INTERFLOW	2.00	1.00	0.00
L	150	150	100
SS	0.02	0.03	0.20
NN	0.30	0.30	0.25
IRC	0.50	0.30	0.50
KV	0.50	0.00	0.00
KK24	0.99	0.99	0.50

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